CHEMICAL CALCULATIONS

Antoine Laurent Lavoisier (1743–1794). "It was left to Lavoisier to transform a philosophical tenet (Law of Conservation of Matter) into a fruitful scientific principle, and to apply it to the interpretation of chemical phenomena." BERTHELOT, *La Révolution Chimique.*

CHEMICAL
CALCULATIONS

A SYSTEMATIC PRESENTATION OF THE SOLUTION OF
TYPE PROBLEMS, WITH 1000 CHEMICAL PROBLEMS
ARRANGED PROGRESSIVELY ACCORDING TO
LESSON ASSIGNMENTS

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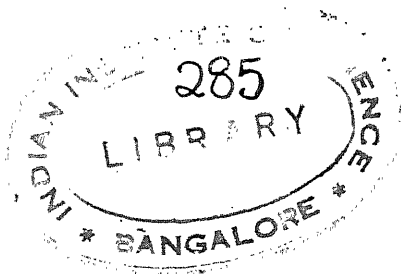
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Chemistry textbooks intended to be used in high school and beginning college classes have been found by many teachers to contain rather too few problems in the mathematics of the subject. Yet in chemistry examinations given under state supervision, as in New York, and in college entrance examinations perhaps three questions out of ten require mathematical calculations. It was primarily to strengthen the hands of teachers by overcoming a deficiency in some of the basal texts in chemistry that this book of Chemical Calculations was prepared

PREFACE

In an investigation of the results secured in the teaching of high school chemistry, conducted in 1922 by Professor Samuel R. Powers of Teachers College, Columbia University, one of the outstanding weaknesses found was the inability of the pupils to use chemical arithmetic. Professor Powers writes concerning the first-year chemistry students in the schools examined that "fewer than 60 per cent are able to compute the molecular weight of gases when the weight of a liter of the gas is given, less than 50 per cent are able to calculate a formula from the molecular weight and percentage composition, and only 40 per cent are able to make the calculations involving a knowledge of Boyle's Law. About one out of three is able to calculate from the percentage composition the ratio between the amounts of oxygen in the two oxides of sulfur. A little more than 10 per cent are able to calculate from the percentage composition the ratio between the amounts of oxygen in the two oxides of nitrogen. Certainly these percentages would be smaller if all the coöperating schools had used this test. The test was used by *distinctly superior schools*."

The reasons for this weakness are not difficult to find. A study of the various textbooks on elementary chemistry reveals in most of them only a passing reference to the subject; or, when a more comprehensive treatment is given, both teacher and pupil are handicapped by a dearth of properly graded problems to go hand in hand with the regular daily lesson assignment. Very few teachers give their students a systematic presentation of chemical calculations.

The aim of this book is to fill the gap which teachers of chemistry in secondary schools have felt exists in most of the textbooks used. To vitalize chemistry and make it a more

workable science has stimulated teachers to introduce the solving of chemical problems, and the trend of the last few years seems to be toward more mathematical chemistry. By this method chemistry becomes an exact science to the student, since he soon realizes that quantitative data are fundamental and that even the minutest particles of matter in their reactions obey mathematical laws.

The problems in this book are progressively arranged according to a number of types which the student soon learns to recognize. They are also graded according to degree of difficulty and order of lesson assignment. A minimum of algebra is required. Since the purpose is to teach not mathematics but chemistry, arithmetical calculations have been reduced to a minimum. Whole numbers are used for the atomic weights of the elements. The constant changing of atomic weights as issued by the International Committee, and the recent researches on isotopes, justify this practice. The student is spared the labor of wading through a maze of cold figures. The time saved in working out problems that involve a multitude of figures can be used in doing other problems.

In analytical work, however, it is often necessary to deal with a large number of figures with a fine degree of accuracy. Rapid solutions must be obtained to save the time of the chemist. For such work the Chemists' Slide Rule (sold by Keuffel & Esser Company) is recommended. Besides the CD and CI scales, this slide rule has two sets of scales with the symbols and formulas of commonly used elements and compounds marked at the points representing their respective atomic and molecular weights, thus making unnecessary the use of atomic and molecular weight tables.

This book is designed primarily to accompany any of the more recent textbooks on general chemistry. Part II has

been added for use by first-year college students, and in those high schools where courses in qualitative and quantitative analysis are offered.

The author wishes to express his gratitude, for helpful advice and suggestions, to Mr. S. Jaffe of the Boys' High School, Brooklyn, New York; Mr. M. Mendel of the Thomas Jefferson High School, Brooklyn, New York; and Mr. M. Dunay, his colleague at the Jamaica High School.

BERNARD JAFFE

SUGGESTIONS FOR THE USE OF THIS BOOK

1. *Aim.* This book aims to cultivate a method of attack on mathematical problems in chemistry. With a knowledge of the ten types of problems presented in Part I, the student will find little trouble in solving practically all the common chemical problems.

2. *Scope.* It is the opinion of the author that all of Part I should be mastered by every high school student. Part II is, on the whole, intended for more mature students, especially first-year college students.

3. *Time to begin.* The introduction of quantitative laws should be reached as early as possible. This book should then be used in conjunction with the regular textbook. The general procedure is to begin the study of the first-type problem about the fourth week after the beginning of the course and after elements, compounds, chemical changes, law of definite proportions, oxygen, hydrogen, law of multiple proportions, and the Atomic Hypothesis have been studied. Valency and the writing of balanced equations should be introduced early.

4. *Rate of progress.* No rigid rules can be set down. It depends upon the position of chemistry in the school curriculum, the age and mental attainments of the pupils, the size of classes, and other varying factors. The work should not be given in too large doses. In schools operated on the Dalton or the Winnetka Plan this book is especially valuable, as it meets the needs of the individual student.

5. *Lesson assignments.* The book follows the order of topics which have become more or less standard in the teaching of chemistry. The student should master each type problem before passing on to the next one. Problems should be
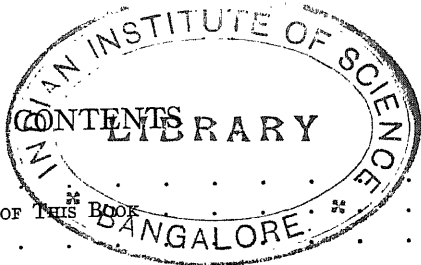
assigned daily from Part III to vitalize the lesson. The problems under each topic in Part III cover various type problems. They have been selected to teach chemical facts. Problems from the Regents Examinations and the College Entrance Board Examinations should be assigned from time to time to give the student confidence in his ability to solve such problems.

6. *Problem book.* All problems should be done by the student in a special problem book. Problems should be discussed in class the following day and necessary corrections made. This develops clear thinking. The proper handling of these problems can serve as a review.

7. *Review work.* The topical arrangement of Part III facilitates reviews. The important equations clarify the student's knowledge of laboratory and commercial preparations and fix in his mind the chemical properties and uses of the substances studied. Part III should prove of great value in the final review.

8. *Answer book.* A pamphlet containing the answers to all the problems may be obtained by teachers from the publishers.

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INTRODUCTION

MANY years' teaching of secondary school chemistry has proved to me the need of such a book on Chemical Calculations as Mr. Jaffe presents. A well-thought-out problem illustrating a chemical principle is just as important in vitalizing the teaching of chemistry as a well-presented demonstration. The progressive arrangement of Mr. Jaffe's problems and the clearness with which the type problems are explained should prove a boon not only to the high school student but to the first-year college student as well.

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CHEMICAL CALCULATIONS

PART ONE

CHAPTER ONE

STRUCTURE OF MATTER

As far as we know today, all matter is made up of one or more of 92 different elements, 90 of which have already been isolated. An **element** is a distinct species of matter which, with the exception of the radioactive substances, does not under ordinary conditions break down into simpler substances. According to the **Atomic Hypothesis**, advanced by Dalton in 1802 and since proved to be a law, all elements are made up of small particles called **atoms**.

Until recently it was supposed that atoms could not be divided, but now it is believed that they are made of particles of negative and positive electricity. These particles are called **electrons** and **protons** respectively. An atom is composed of a positively charged nucleus, which contains an excess of protons, and of one or more electrons which are placed at a distance from the nucleus. The nucleus is small when compared with the total diameter of the space occupied by the atom.

The atoms of the same element are alike, but differ from the atoms of other elements in the number of positive and negative charges composing them. The simplest atom, that of hydrogen, is considered to be made up of one positive charge, the **proton**, and one electron, which is in vibratory motion and functions when chemical union takes place.

The weight of the individual atom of even the heaviest element known is so exceedingly small (estimated at a million

millionth of a million millionth of a gram) that it would be extremely cumbersome to use such a number. Chemists have therefore arranged the elements according to the **relative** weights of the atoms, and we call this arrangement the Table of Atomic Weights of the Elements (page 149). Since oxygen unites with nearly all the elements, forming oxides which can easily be analyzed, chemists have given to oxygen the arbitrary weight of 16, which makes the relative weight of hydrogen 1.008, or approximately 1. Hydrogen is the lightest of all the elements, hence the atomic weights of all the elements are greater than unity, and nearly all of them are approximately whole numbers.

Atoms have the power of combining with atoms of the same element or of other elements to form **molecules**, which are aggregations of atoms chemically combined and possessing properties quite different from those of the elements which compose them. When atoms of different elements combine chemically, we call the products **compounds**.

It is a great convenience to have a shorthand method of representing elements and compounds. We call the abbreviated form of an element its **symbol**. Thus H is the symbol of hydrogen. We call the abbreviated form of a compound its **formula**, and we write it by joining the symbols of the elements which compose it. Thus NaCl represents the formula of sodium chloride.

When we bring together various substances and form **mixtures** without combining them chemically, we may form these mixtures in any proportions whatever. In chemical union the experimenter has no choice in the matter. The proportions are determined by the substances themselves. This is the most striking fact of chemical combinations. This peculiar behavior is stated as the **Law of Definite Proportions**.

We often find a series of compounds which show varying proportions of the same elements. In such cases we find that the elements follow the **Law of Multiple Proportions**, which may be stated as follows: Whenever two elements, A and B, combine to form more than one compound, if we take a fixed weight of A, then the weights of B which unite with this fixed weight of A are in the ratio of small whole numbers.

PROBLEMS BASED ON THE LAW OF MULTIPLE PROPORTIONS

EXAMPLE. Nitrogen and oxygen unite to form five different compounds, whose compositions are given in the following table. The figures in the second and third columns are determined by experiment and from these the ratio of small whole numbers in the fourth column is found.

COMPOUNDS	FIXED WEIGHTS OF A (NITROGEN)	WEIGHTS OF B (OXYGEN)	RATIO OF WEIGHTS OF B IN DIFFERENT COMPOUNDS
Nitrous oxide	28 g. of N	16 g. of O	16 to 32 to
Nitric oxide	28 g. of N	32 g. of O	48 to 64 to
Nitrogen trioxide	28 g. of N	48 g. of O	80 or
Nitrogen peroxide	28 g. of N	64 g. of O	1 to 2 to 3
Nitrogen pentoxide	28 g. of N	80 g. of O	to 4 to 5

1. **Problem.** Manganese and oxygen form five oxides: manganous oxide (MnO), manganic oxide (Mn_2O_3), manganese dioxide (MnO_2), manganese trioxide (MnO_3), and manganese heptoxide (Mn_2O_7). Do manganese and oxygen obey the Law of Multiple Proportions?

COMPOUNDS	FIXED WEIGHTS OF A	WEIGHTS OF B	RATIO OF WEIGHTS OF B IN DIFFERENT COMPOUNDS
Manganous oxide	110 g. of Mn	32 g. of O	
Manganic oxide	110 g. of Mn	48 g. of O	
Manganese dioxide	110 g. of Mn	64 g. of O	
Manganese trioxide	110 g. of Mn	96 g. of O	
Manganese heptoxide	110 g. of Mn	112 g. of O	

2. **Problem.** Iron and oxygen form three compounds: ferrous oxide (FeO), ferric oxide (Fe_2O_3), and magnetic oxide of iron (Fe_3O_4). Do iron and oxygen obey the Law of Multiple Proportions if the compositions of their compounds are as follows?

COMPOUNDS	FIXED WEIGHTS OF A	WEIGHTS OF B	RATIO OF WEIGHTS OF B IN DIFFERENT COMPOUNDS
Ferrous oxide	168 g. of Fe	48 g. of O	
Ferric oxide	168 g. of Fe	72 g. of O	
Magnetic oxide	168 g. of Fe	64 g. of O	

CHAPTER TWO

PROBLEMS OF TYPE I: TO FIND THE MOLECULAR WEIGHT OF A COMPOUND FROM ITS FORMULA

THE symbol of an element stands for more than the name of the element. It designates a **definite weight**. Ag means one weight of silver, one atomic weight of silver, or 108 grams of silver.

The **molecular weight** of a compound is equal to the sum of the weights of all the atoms it contains. The atomic weights used are the relative atomic weights; hence the molecular weights obtained are really the relative molecular weights.

A. EXAMPLE. To find the molecular weight of potassium bromide, KBr. *Place the approximate atomic weights (page 150) under the symbols and add them.*

   K   Br
   $39 + 80 = 119 =$ molecular weight of KBr

Very often the molecule of a compound or even of an element contains more than one atom of a particular element. We represent the number of these atoms by a **subscript** or small number placed in the lower right corner of the symbol of that element. Thus H_2O represents a molecule of water made up of 2 atoms of hydrogen and 1 atom of oxygen. The subscript 1 is never written; it is always understood.

B. EXAMPLE. Find the molecular weight of magnesium sulfate, $MgSO_4$. *Be sure to multiply the atomic weight of every element followed by a subscript by the subscript.*

   Mg   S O_4
   $24 + 32 + 16 \times 4 = 24 + 32 + 64 = 120 =$ molecular weight

To represent more than one molecule of an element or compound, we place a **coefficient** in front of its formula. This coefficient multiplies the number of every atom in the substance. Thus $5CuSO_4$ stands for 5 molecules of copper sul-

fate, each molecule consisting of one atom of copper, one of
sulfur, and four of oxygen. In the 5 molecules, then, there
are 5 atoms of copper, 5 of sulfur, and 20 atoms of oxygen.

C. EXAMPLE. Find the molecular weight of $2CaCO_3$ (calcium carbonate).
Be sure to multiply everything after the coefficient by the coefficient.

$$2Ca \quad C \quad O_3$$
$$2(40 + 12 + 16 \times 3) \quad \text{or}$$
$$2(40 + 12 + 48)$$
$$2(100) \qquad \qquad = 200 = \text{weight of 2 molecules of}$$
$$\text{calcium carbonate}$$

A **radical** is a group of elements acting chemically like a
single element. For example, NH_4 is called the ammonium
radical, and NO_3 is the nitrate radical. When a compound
contains more than one of the same radicals in its molecule,
a subscript is written in such a way as to multiply every atom
in that radical. This is done by enclosing the radical in
parentheses and placing the subscript outside of these paren-
theses. Thus $(NH_4)_2S$ represents one molecule of ammonium
sulfide containing 2 ammonium radicals and 1 atom of sulfur;
or all together, 2 atoms of nitrogen, 8 atoms of hydrogen, and
1 atom of sulfur.

D. EXAMPLE. Find the molecular weight of lead nitrate, $Pb(NO_3)_2$.
*Remember that the subscript multiplies only the element or radical immediately
preceding it.*

$$Pb \quad (N \qquad O_3)_2$$
$$207 + (14 + 16 \times 3)2$$
$$207 + (14 + 48)2$$
$$207 + (62)2$$
$$207 + 124 = 331 = \text{molecular weight of } Pb(NO_3)_2$$

Compounds may contain water chemically combined in a
definite proportion by weight. This water is called **water of
crystallization**, and is written after the anhydrous compound
followed by a dot. Thus, crystallized sodium carbonate

(washing soda) contains 10 molecules of water of crystallization and its formula is $Na_2CO_3 \cdot 10H_2O$. This molecule contains 2 atoms of sodium, 1 of carbon, 20 of hydrogen, and 13 of oxygen. A dot or period in a formula stands for a plus sign.

E. EXAMPLE. Find the molecular weight of crystallized ferrous sulfate.

$$Fe \quad S \quad O_4 \cdot \quad 7 \quad H_2 \quad O$$
$$56 + 32 + 16 \times 4 + 7(1 \times 2 + 16)$$
$$56 + 32 + 64 + 7(18)$$
$$56 + 32 + 64 + 126$$
$$278 = \text{molecular weight of } FeSO_4 \cdot 7H_2O$$

Problems

3. Find the molecular weights of sodium bromide, NaBr, and potassium iodide, KI.
4. Determine the molecular weights of lithium chloride, LiCl, and zinc sulfide, ZnS.
5. Find the molecular weights of zinc sulfate, $ZnSO_4$, copper carbonate, $CuCO_3$, and calcium sulfate, $CaSO_4$.
6. What are the molecular weights of manganese dioxide, MnO_2, and potassium sulfate, K_2SO_4?
7. What are the molecular weights of copper hydroxide, $Cu(OH)_2$, nickel nitrate, $Ni(NO_3)_2$, and calcium bicarbonate, $Ca(HCO_3)_2$?
8. Determine the molecular weights of crystallized barium chloride, $BaCl_2 \cdot 2H_2O$, and hypo, $Na_2S_2O_3 \cdot 5H_2O$ (page 102).
9. What are the molecular weights of calcium phosphate, $Ca_3(PO_4)_2$, and gypsum, $CaSO_4 \cdot 2H_2O$?
10. Find the molecular weights of $2Na_2B_4O_7 \cdot 10H_2O$, and plaster of Paris, $(CaSO_4)_2 \cdot H_2O$.
11. The formula for Glauber's salt is $Na_2SO_4 \cdot 10H_2O$. Find the molecular weight of 5 molecules of this substance.

CHAPTER THREE

PROBLEMS OF TYPE II: TO FIND THE PERCENTAGE COMPOSITION OF A COMPOUND FROM ITS FORMULA

To find the percentage composition of a compound is to find the percentage of each different element present in the compound. *Hence we divide the weight of each element by the molecular weight of the compound and multiply the fraction thus obtained by 100.*

A. EXAMPLE. Find the percentage composition of potassium chlorate, $KClO_3$.

$$\begin{array}{ccc} K & Cl & O_3 \end{array}$$
$$39 + 35.5 + 16 \times 3 = 122.5 = \text{molecular weight of } KClO_3$$

$$\text{Percentage of potassium} = \frac{\text{Wt. of K}}{\text{Mol. Wt. of } KClO_3} \times 100 = \frac{39}{122.5} \times 100 = 32\%$$

$$\text{Percentage of chlorine} = \frac{\text{Wt. of Cl}}{\text{Mol. Wt. of } KClO_3} \times 100 = \frac{35.5}{122.5} \times 100 = 29\%$$

$$\text{Percentage of oxygen} = \frac{\text{Wt. of 3 atoms of O}}{\text{Mol. Wt. of } KClO_3} \times 100 = \frac{16 \times 3}{122.5} \times 100 = 39\%$$
$$\overline{100\%}$$

As a check see that the total is approximately 100%.

B. EXAMPLE. Find the percentage composition of $Na_2SO_4 \cdot 10H_2O$.

$$\begin{array}{cccccc} Na_2 & S & O_4 & .10 & H_2 & O \end{array}$$
$$23 \times 2 + 32 + 16 \times 4 + 10(1 \times 2 + 16) = 322 = \text{Mol. Wt. of the compound}$$

Now find the total atomic weight of each separate element in the compound. Thus:

$$\begin{array}{llll} \text{Sodium} & = 2 \text{ atoms} & = 23 \times 2 & = 46 & = \text{total atomic weight} \\ \text{Sulfur} & = 1 \text{ atom} & = 32 & = \text{total atomic weight} \\ \text{Oxygen} & = 14 \text{ atoms} & = 16 \times 14 & = 224 & = \text{total atomic weight} \\ \text{Hydrogen} & = 20 \text{ atoms} & = 1 \times 20 & = 20 & = \text{total atomic weight} \end{array}$$

Sum of the atomic weights $= 322 = $ Mol. Wt. of the compound

Now the percentage of Na $= \frac{46}{322} \times 100 = 14.3\%$
the percentage of S $= \frac{32}{322} \times 100 = 10.0\%$
the percentage of O $= \frac{224}{322} \times 100 = 69.5\%$
the percentage of H $= \frac{20}{322} \times 100 = \underline{6.2\%}$
Total $= \overline{100\%}$

Problems

12. Calculate the percentage composition of the following compounds:
(a) water, H_2O, (b) mercuric oxide, HgO, (c) iron oxide, Fe_2O_3.
13. Find the percentage composition of (a) gypsum, $CaSO_4 \cdot 2H_2O$,
(b) phosphorus pentoxide, P_2O_5, (c) sulfuric acid, H_2SO_4, (d) zinc
sulfate, $ZnSO_4$.
14. Calculate the percentage composition of chrome alum, $KCr(SO_4)_2 \cdot$
$12H_2O$, crystallized potassium sulfate, $K_2SO_4 \cdot 10H_2O$, and $NiSO_4 \cdot$
$(NH_4)_2SO_4 \cdot 6H_2O$.
15. Determine the percentage composition of borax, $Na_2B_4O_7 \cdot 10H_2O$,
and of crystallized potassium ferrocyanide, $K_4Fe(CN)_6 \cdot 3H_2O$.
16. What percentage of oxygen is contained in crystallized potassium
magnesium sulfate, $K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$?

C. EXAMPLE.   Find the weight of iron in 50 lb. of an ore containing 80% ferric
oxide, Fe_2O_3.

Since only 80% of the ore is Fe_2O_3, the weight of Fe_2O_3 is 80% of 50 lb., or
40 lb.

$\quad$ Fe$_2$ $\quad$ O$_3$
$56 \times 2 + 16 \times 3$
$56 \times 2 + 16 \times 3 = 160 = $ Mol. Wt.
Percentage of Fe $= \frac{112}{160} \times 100 = 70\%$

Now the weight of all the Fe_2O_3 present in the ore is 40 lb.

Therefore 70% of 40 lb., or 28 lb., is the weight of the Fe.

Problems

17. Potassium chlorate ($KClO_3$) contains 39% oxygen. How much
oxygen will be found in 100 grams of this compound?
18. How much arsenic (As) is available in 91 lb. of an impure realgar ore
containing 75% of As_2O_2?
19. How much phosphorus (P) can be obtained from 2000 lb. of
$Ca_3(PO_4)_2$?
20. If a skeleton weighs 25 lb. and contains 60% $Ca_3(PO_4)_2$, how much
calcium (Ca) can be obtained from it?
21. How much aluminum (Al) can be obtained from 100 lb. of its cryo-
lite ore which, on analysis, showed the presence of 85% Na_3AlF_6?
22. An ore of zinc contained 70% of $ZnCO_3$. Calculate the amount of
zinc in 100 lb. of this ore.

23. Which ore will give more copper, one containing 95% $CuCO_3$ or one containing 80% of Cu_2S?

24. How much phosphorus can be obtained from 170 tons of bones containing 52.6% of $Ca_3(PO_4)_2$?

25. The skeleton of a man weighs 23.7 lb. and contains 59% of calcium phosphate, $Ca_3(PO_4)_2$. What weight of P can be prepared from this skeleton?

CHAPTER FOUR

VALENCY AND THE WRITING OF FORMULAS

VALENCY is the capacity of an element to unite with other elements. This capacity is measured in terms of the power of its atom to replace one or more atoms of hydrogen. Hydrogen is always univalent. Nitrogen, one atom of which combines with three atoms of hydrogen, has a valency of three. Valency is fixed after we have experimentally determined atomic weights and found the composition of compounds. A knowledge of the valency of different elements and radicals is almost indispensable in the writing of formulas. Valencies must be memorized.

VALENCY RULES IN THE WRITING OF FORMULAS

1. Place the valency of the element as $+$ or $-$ signs over the symbol. The subscript after each element or radical should be the same as the number of $+$ or $-$ signs over the other element or radical. EXAMPLE. The formula for antimony sulfide is $\overset{+++}{Sb_2}\overset{--}{S_3}$. The formula for copper nitrate is $\overset{++}{Cu}\overset{-}{(NO_3)_2}$.

2. Whenever the subscripts are the same, they are omitted. EXAMPLE. Ferric phosphate is written $FePO_4$ and not $\overset{+++}{Fe_3}\overset{---}{(PO_4)_3}$. This rule is followed **unless** the subscripts represent the actual molecular structure of the compound. Thus the formula of nitrogen peroxide is N_2O_4 and not NO_2, since the molecule of nitrogen peroxide contains 2 atoms of N and 4 atoms of O.

TABLE OF VALENCIES

	MONOVALENT	DIVALENT	TRIVALENT	TETRAVALENT
Electropositive elements + (Metals)	Hydrogen (H)· Copper(ous) (Cu)· Lithium (Li)· Mercury(ous) (Hg)· Potassium (K)· Silver (Ag)· Sodium (Na)·	Barium (Ba)·· Cadmium (Cd)·· Calcium (Ca)·· Cobalt(ous) (Co)·· Copper(ic) (Cu)·· Iron(ous) (Fe)·· Lead (Pb)·· Magnesium (Mg)·· Manganese(ic) (Mn)·· Mercury(ic) (Hg)·· Nickel(ous) (Ni)·· Tin(stannous) (Sn)·· Zinc (Zn)··	Aluminum (Al)··· Antimony (Sb)··· Arsenic (As)··· Bismuth (Bi)··· Boron (B)··· Chromium (Cr)··· Cobalt(ic) (Co)··· Gold (Au)··· Iron(ferric) (Fe)··· Nickel(ic) (Ni)···	Platinum (Pt)···· Tin(ic) (Sn)····
Electropositive radicals +	Ammonium (NH₄)·			
Electronegative elements − (*Non-metals*)	Bromine (Br)⁻ Chlorine (Cl)⁻ Iodine (I)⁻ Fluorine (F)⁻	Oxygen (O)⁼ Sulfur (S)⁼	Nitrogen (N)⁻⁻⁻ Phosphorus (P)⁻⁻⁻	Carbon (C)⁻⁻⁻⁻ Silicon (Si)⁻⁻⁻⁻ Sulfur (S)⁻⁻⁻⁻
Electronegative radicals −	Acetate (C₂H₃O₂)⁻ Bicarbonate (HCO₃)⁻ Chlorate (ClO₃)⁻ Hydroxyl (OH)⁻ Nitrate (NO₃)⁻ Nitrite (NO₂)⁻	Carbonate (CO₃)⁼ Sulfate (SO₄)⁼ Sulfite (SO₃)⁼ Tartrate (C₄H₄O₆)⁼	Ferricyanide [Fe(CN)₆]⁻⁻⁻ Phosphate (PO₄)⁻⁻⁻	Ferrocyanide [Fe(CN)₆]⁻⁻⁻⁻

3. A radical acts like an element, has its characteristic va-
   lency, and usually passes through a chemical reaction un-
   changed. It should be placed in parentheses if followed
   by a subscript greater than unity.

4. The common practice in the writing of formulas is to place
   the metal, metallic radical, or more electropositive element
   first, followed by the non-metal, non-metallic radical or less
   electropositive element. Thus we write $\overset{+}{K}\overset{-}{Cl}$ and not $\overset{-}{Cl}\overset{+}{K}$.

Problems

26. Write the formulas of the following compounds: calcium nitrate,
    aluminum phosphate, mercurous chloride, nickel sulfide.

27. Make a list of all the salts of calcium in the Practice Table of Valen-
    cies on page 158.

28. Write the formulas for calcium sulfide, barium chlorate, ferric
    ferrocyanide, sodium ferricyanide, copper acetate.

29. Make a list of all the salts of aluminum which are theoretically
    possible (see Valency Practice Table, page 158).

30. Make a list of as many of the sulfites of the metals as are theoreti-
    cally possible.

31. Prepare a table of as many of the salts of iron (ferric) as are theoreti-
    cally possible.

32. Make a list of all the sulfides of the common metals.

33. Write the formulas of sodium potassium tartrate, silver tartrate,
    sodium hydrogen carbonate, and ammonium hydrogen tartrate.

CHAPTER FIVE

PROBLEMS OF TYPE III: TO FIND THE SIMPLEST FORMULA OF A COMPOUND FROM ITS PERCENTAGE COMPOSITION

WHEN we already know the elements present in the compound, all we need to find is the number of atoms of each of these elements present in the molecule.

The percentage of each element in the compound is divided by the atomic weight of that element. The quotients are then examined and divided by their highest common factor (H.C.F.); that is, by the largest number which will divide each of the quotients and give a whole number. These numbers are not always exactly whole numbers, but approximate, and are regarded as integers. They represent the **number of atoms** of the respective elements in the compound.

The **simplest formula** is thus obtained. In writing the formula we inspect the elements and arrange them so that the electropositive element or radical comes first, followed by the negative element or radical. We must learn to pick out those elements which may form radicals. Thus a compound whose composition showed 1 atom of copper, 1 atom of sulfur, and 4 atoms of oxygen is written as $CuSO_4$, since SO_4 is the negative sulfate radical.

A. EXAMPLE. Find the simplest formula of a compound which contains 63.6% nitrogen and 36.4% oxygen.

For N, $\dfrac{\text{Percentage composition of N}}{\text{Atomic weight of N}} = \dfrac{63.6}{14} = 4.51$

$\dfrac{4.51}{2.28} = 2$

H.C.F = 2.28

For O, $\dfrac{\text{Percentage composition of O}}{\text{Atomic weight of O}} = \dfrac{36.4}{16} = 2.28$

$\dfrac{2.28}{2.28} = 1$

The numbers 2(N) and 1(O) represent the smallest number of the respective elements in the compound.

The simplest formula is, therefore, $(N_2O)_x$.

This may not be the true formula, since any multiple of this formula may be the actual formula. N_4O_2, or N_6O_3 will just as well satisfy the percentage composition as given in the problem. Temporarily, therefore, we will designate this formula in parentheses, followed by x as the simplest formula. Later on, under Problems of Type VII, we shall be in a position to determine the true formula when we shall be in command of additional data.

Problems

34. Calculate the simplest formula of a compound containing 7.69% hydrogen and 92.31% carbon.
35. A compound contains 1% hydrogen, 11.99% carbon, 47.95% oxygen, and 39.06% potassium. Calculate its simplest formula.
36. Acetic acid consists of 40% carbon, 6.67% hydrogen, and 53.33% oxygen. Determine its simplest formula.
37. A gas on analysis gave 96.75% iodine, 3% carbon, and 0.25% hydrogen. What is the simplest formula of this compound?
38. An oxide of barium gave on analysis 81% barium, and 19% oxygen. What is its simplest formula?
39. 63.2 parts of manganese and 36.8 parts of oxygen are found in 100 parts of an oxide of manganese. What is the simplest formula of this oxide?
40. What is the simplest formula of a substance whose composition is calcium, 40%; carbon, 12%; and oxygen, 48%?
41. What is the simplest formula of a compound which on analysis showed the following composition: carbon, 54.55%; hydrogen, 9.09%; and oxygen, 36.36%?

Sometimes the percentage composition of a compound is not given directly but from the facts of the problem we can find this percentage composition and then proceed as above.

B. Example. 168 lb. of iron when oxidized produced 240 lb. of iron oxide. Find the simplest formula of this oxide.

The difference between the weights of iron oxide and iron will be the weight of the oxygen. Hence the weight of the oxygen is $240 - 168$, or 72 lb.

$$\text{For iron} = \frac{\% \text{ comp. of Fe}}{\text{At. Wt. of Fe}} = \frac{\frac{168}{240} \times 100}{56} = \frac{70}{56} = 1.12$$

$$\text{For oxygen} = \frac{\% \text{ comp. of O}}{\text{At. Wt. of O}} = \frac{\frac{72}{240} \times 100}{16} = \frac{30}{16} = 1.88$$

$$\frac{1.12}{0.6} = 2$$

H.C.F. $= 0.6$

$$\frac{1.88}{0.6} = 3$$

Hence 2 and 3 are the smallest numbers of atoms of Fe and O in the molecule. Therefore the simplest formula is $(Fe_2O_3)_x$.

Problems

42. 50 grams of mercury were completely converted into mercuric oxide, yielding 54 grams of HgO. Prove that this is its simplest formula.
43. 219 grams of hydrogen chloride were formed by the union of 6 grams of hydrogen and 213 grams of chlorine. What is the simplest formula of this compound?
44. Bromine was allowed to act upon hot copper until it changed 32 grams of the metal into 112.5 grams of copper bromide. What is the simplest formula of this compound?
45. 70 grams of nitrogen completely united with hydrogen gas and furnished 85 grams of ammonia. Find the simplest formula of ammonia.

NOTE. Problems of this type can be checked by finding the percentage composition of the formulas as found. This percentage composition should, of course, agree with the data given. Thus, in Example A, page 14, the percentage composition of N_2O is found to be:

$$\text{For N, } \frac{2 \times 14}{28 + 16} = \frac{28}{44} = 63.6\%$$

$$\text{For O, } \frac{16}{28 + 16} = \frac{16}{44} = 36.4\%$$

which is the same as given in the problem.

CHAPTER SIX

GASES AND THEIR MEASUREMENT

GASES are composed of molecules in constant and rapid motion. These particles, being at considerable distances from one another, may be brought closer together by exerting pressure upon them. The more pressure exerted, the nearer the particles and hence the smaller the volume the gas will occupy. Double the pressure and you decrease the volume to half. This behavior of gases is expressed by **Boyle's Law** (1660) which states that the **volume of a gas varies inversely as the pressure, when the temperature remains the same,** or,

$$pv = p'v' \quad . \quad . \quad . \quad (1)$$

where p and v stand for the original pressure and volume and p' and v' for the new pressure and volume.

To measure the pressure of the atmosphere, scientists make use of the **barometer** (Fig. 1), consisting of a tube of mercury completely filled and then inverted in a reservoir filled with the same heavy liquid. The average height of the mercury in this tube, at sea level, is 760 millimeters (mm.), or about 30 inches. This is known as **standard pressure** or the pressure of
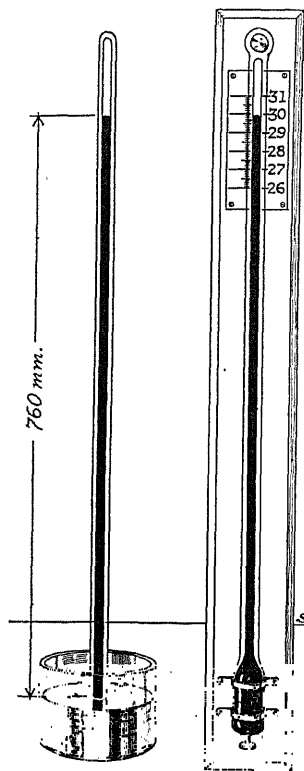
FIG. 1.

1 atmosphere, and represents the weight of the gases in the atmosphere which are pressing down upon every square centimeter of the earth (equivalent to almost 15 lb. per square inch). This column of air is capable of supporting an equal weight of liquid mercury in the barometer.

A rise in temperature increases the speed of the particles composing a gas and hence the gas tends to expand and occupy more space. It has been found that with every lowering of 1° C. from the zero point a gas contracts $\frac{1}{273}$ of its volume. Theoretically, then, at − 273° the gas should cease to exist. Since all gases change to liquids before this extremely low temperature is reached, we have not been able to verify this conclusion. However, we call this temperature of − 273° C. the zero of the **absolute temperature or T. scale.**

The law expressing the change of volume of a gas due to a temperature change is known as **Charles' Law** (1787) and states that **the volume of a gas varies directly as the absolute temperature, provided the pressure remains the same.**[1] By formula we express it as

$$\frac{v}{T} = \frac{v'}{T'} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (2)$$

where v and T stand for the original volume and absolute temperature, and v' and T' stand for the new volume and absolute temperature.

Since gases are measured under varying conditions of temperature and pressure, and since the gas laws operate only under certain conditions, it is necessary to correct our gas measurements to correspond to those obtaining under **standard conditions of 0° C. and 760 mm. pressure.** We can correct

---

[1] There are certain deviations from these gas laws whose discussion is beyond the scope of this book. Only ideal gases follow the laws as stated above.

for both temperature and pressure simultaneously by combining equations (1) and (2) above, as follows:

$$\frac{pv}{T} = \frac{p'v'}{T'}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

PROBLEMS OF TYPE IV: TO REDUCE GAS MEASUREMENTS TO STANDARD CONDITIONS

A. *Change in volume due to change in pressure (temperature constant)*

EXAMPLE. A quantity of chlorine gas occupies a volume of 50 cc. when the barometer reads 740 mm. What would its volume be under standard conditions?

The temperature is not mentioned and we assume that it does not change. Substituting in equation (1) we have:

$$pv = p'v'$$
$$740(50) = 760(x)$$
$$37000 = 760\,x$$
$$x = 48.7 \text{ cc. of chlorine}$$

Alternate method. Since standard pressure is greater than the pressure given, the volume of the gas will be smaller; i.e., $\frac{740}{760} \times 50$, or 48.7 cc.

Problems

46. 400 cc. of acetylene gas were measured under an atmospheric pressure of 765 mm. The gas was then subjected to a pressure of 790 mm. What new volume did the gas occupy?

47. Ammonia gas (NH_3) when measured under standard conditions (760 mm.) occupied 4.5 liters. The pressure then changed to 745 mm. What was the volume occupied by the gas after this change in pressure?

48. The pressure on 35 cc. of carbon monoxide gas (CO) was suddenly changed from 765 mm. to 770 mm. What new volume did the gas occupy?

49. The pressure on a balloon containing 10,000 cubic meters of helium gas was changed from 760 mm. to 730 mm. What was the new volume of the balloon?

B. *Change in volume due to change in temperature (pressure constant)*

EXAMPLE. A quantity of carbon dioxide gas measured 450 cc. when the room temperature was 22° C. What would its volume be under standard conditions?

The pressure is not mentioned, so we assume we are working under standard or 760 mm. pressure. Substitute in equation (2)

$$\frac{v}{T} = \frac{v'}{T'}$$

$$\frac{450}{273 + 22} = \frac{x}{273}$$

$$\frac{450}{295} = \frac{x}{273}$$

$$295 \, x = 450(273)$$

$$x = 416.4 \text{ cc. of carbon dioxide}$$

Alternate method. Since standard temperature is lower than the temperature at which we are working, the volume of the gas will be lower at this lower temperature. Hence the volume will be

$$\frac{273}{273 + 22} \times 450 \text{ cc. or} \frac{273(450)}{295} = 416.4 \text{ cc.}$$

Problems

50. While the pressure on 500 cc. of hydrogen gas remained steady, the temperature was changed from 20° C. to 0° C. What change in volume resulted?

51. Hydrogen sulfide was measured at 18° C. and found to occupy 15.5 cc. Next day the temperature of the gas was found to be 14.5° C. What volume did the gas occupy at this lower temperature?

52. Methane gas, CH_4, was measured at 0° C. and at 40° C. At the lower temperature the volume was 22.5 cc. What volume did the gas occupy at the higher temperature?

C. *Change in volume due to simultaneous change in temperature and pressure*

EXAMPLE. At 27° C. and 800 mm. pressure a quantity of nitrogen gas measured 20 cc. What would the volume be under standard conditions?

Substituting in equation (3),

$$\frac{pv}{T} = \frac{p'v'}{T'}$$

$$\frac{800(20)}{273 + 27} = \frac{760(x)}{273}$$

$$800(20)(273) = 760(300)\ x$$

$$x = \frac{800(20)(273)}{760(300)}$$

$$x = 19.2 \text{ cc. of nitrogen}$$

Problems

53. Reduce to standard conditions 48 cc. of nitrogen, measured at 18° C. and 765 mm.
54. Under standard conditions a volume of oxygen gas occupied 1 liter. Find the volume of this gas when measured at 17° C. and 770 mm.
55. Hydrogen chloride gas was subjected to a pressure of 1000 mm. and occupied a volume of 53 cc. at 30° C. Determine the volume of the gas under standard conditions.
56. Bromine vapor occupied 2.5 liters when measured at 57° C. and 780 mm. What theoretical volume would the vapor occupy if it were measured at 17° C. and 750 mm.?
57. A gram of gunpowder produced, on exploding, 300 cc. of gases when measured under standard conditions. What volume would these gases occupy at the temperature produced by the explosion (2200° C.)?

CORRECTION OF GAS VOLUMES FOR AQUEOUS VAPOR PRESSURE

If we are measuring the volume of a gas collected over water at 20° C. and 760 mm., the gas is saturated with water vapor, which, according to the table of aqueous vapor pressure, exerts its own pressure of 17.4 mm. Since 760 mm. represents the sum of the aqueous pressure and the gas pressure, the pressure of the dry gas is only 760 minus 17.4, or 742.6 mm. (Fig. 2).
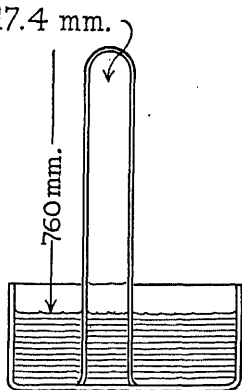
Fig. 2. The corrected atmospheric pressure within the tube is 760 mm. minus 17.4 mm. (water-vapor pressure at 20° C.), or 742.6 mm.

PRESSURE OF WATER VAPOR, OR AQUEOUS TENSION

(In millimeters of mercury)

TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE
0.0° C.	4.6 mm.	21.5° C.	19.1 mm.
5	6.5	22.	19.7
10	9.2	22.5	20.3
10.5	9.5	23.	20.9
11	9.8	23.5	21.5
11.5	10.1	24.	22.1
12	10.5	24.5	22.8
12.5	10.8	25.	23.5
13	11.2	25.5	24.2
13.5	11.5	26.	25.0
14	11.9	26.5	25.7
14.5	12.3	27.	26.5
15	12.7	27.5	27.3
15.5	13.1	28.	28.1
16	13.5	28.5	28.9
16.5	14.0	29.	29.8
17	14.4	29.5	30.7
17.5	14.9	30	31.6
18	15.4	40	54.9
18.5	15.9	50	92.1
19	16.4	60	149.2
19.5	16.9	70	233.8
20	17.4	80	355.4
20.5	17.9	90	526.0
21	18.5	100	760.0

Problems

58. 500 cc. of carbon monoxide at 27° C. stand in a measuring tube over water while the barometric pressure is 770 mm. What volume would the gas occupy under standard conditions?

59. 200 cc. of helium is collected in a tube inverted over water. The temperature changes from 17° C. to 27° C. while standard atmospheric pressure remains unchanged. What change in volume does the gas undergo?

60. What change in atmospheric pressure will be necessary to reduce 20 cc. of a gas measured in a eudiometer over water at 17° C. and 760 mm. to a volume of 10 cc. at 27° C.?

CORRECTION OF GAS VOLUMES FOR DIFFERENCE IN LEVEL

If a gas is collected over mercury, before the volume of that gas is read off, the levels of the mercury inside the measuring tube and outside must be the same (Fig. 3, *C*). If, as in *A* (Fig. 3), the level is higher inside the measuring tube than outside, then the gas is under a pressure which is **lower** than barometric pressure by the height *A*. On the other hand, if the levels of the mercury are as represented by *B* (Fig. 3), then the gas is under a **greater** pressure than barometric reading, and the pressure illustrated by height *B* should be added to the barometric reading.

EXAMPLE. What is the corrected pressure under which a gas is measured if the standard barometric reading is 760, but the level of the mercury inside the measuring tube is 1.5 cm. (15 mm.) above the level of the mercury in the reservoir?

The answer is 760 minus 15 mm., or 745 mm.

FIG. 3.

If the gas is collected over water, which is the common laboratory method, the height of the column of water which represents the difference in levels weighs only $\frac{1}{13.6}$ that of mercury, since mercury is 13.6 times as heavy as an equal volume of water.
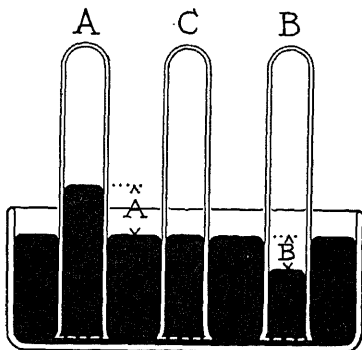
EXAMPLE. Calculate the corrected pressure under which a gas, collected over water, is measured if the level of the water inside the measuring tube is 12 mm. below the level of the water in the reservoir.

The answer is 760 plus $\frac{12 \text{ mm.}}{13.6}$, or approximately 760.9 mm.

Problems

61. A certain quantity of hydrogen gas measured over water gave a volume of 50 cc. at 17° C. and 770 mm. when the level inside 'the measuring tube was 1 cm. above that on the outside. Calculate the corrected volume of gas under standard conditions.

62. Some nitrous oxide is measured over mercury, and when the level of the mercury is 2 cm. lower in the eudiometer than on the outside, the volume of gas is 20 cc. If the measurements were made at 7° C. and 750 mm., what would be the corrected volume under standard conditions?

63. 100 cc. of air stand in a tube over mercury at 10° C. and 760 mm. The level of the mercury within the tube is 8 cm. above that without. What is the volume of the air under standard conditions?

64. 200 cc. of a gas insoluble in water are measured over water at 35° C. and 700 mm. when the level of the water is 30 cm. higher within the tube than without. What is the volume of the gas when it is again measured at 17° C. and 760 mm., and the levels of the water within and without the tube are the same?

65. What change in atmospheric pressure will be necessary to bring a volume of helium gas measured at 27° C. and 770 mm. in a tube over water from 50 cc. to 60 cc., if the temperature remains the same?

CHAPTER SEVEN

PROBLEMS BASED ON THE MOLECULAR STRUCTURE
OF GASES AND VAPORS

In synthesizing water, one volume of oxygen unites with two volumes of hydrogen to form two volumes of water vapor. Gay-Lussac in 1808 studied similar reactions, and advanced the law which states that *the relative combining volumes of gases, and the volumes of their products, if gaseous, can be expressed in a ratio of small whole numbers.*

Gay-Lussac's Law, together with Boyle's and Charles' Laws, led Avogadro in 1811 to advance a theory in explanation of the uniform behavior of all gases. He ascribed the cause of this uniform behavior to the probable fact that *equal volumes of all gases and vapors under the same conditions of temperature and pressure, contain the same number of molecules.* The actual number of these molecules, called Avogadro's number, is staggering. It is about 6×10^{23} molecules per 22.2 liters. (10^{23} is equal to 10 followed by 23 zeros.)

PROOF THAT THE MOLECULE OF HYDROGEN CONTAINS
TWO ATOMS

From experiments we know that 1 volume of hydrogen unites with 1 volume of chlorine, yielding 2 volumes of hydrogen chloride gas, or

$$1 \text{ volume H} + 1 \text{ volume Cl} \longrightarrow 2 \text{ volumes HCl}$$

According to Avogadro's Law, a cubic foot of hydrogen, helium, hydrogen chloride, water vapor, ammonia, or any other gas or vapor contains the same number of molecules. Conversely, equal numbers of molecules would occupy equal volumes. For example, 100 molecules of hydrogen, oxygen,

and hydrogen chloride would all occupy the same volume. Therefore, one molecule of hydrogen and one molecule of chlorine would both occupy equal volumes, whereas two volumes of hydrogen chloride gas would occupy twice this volume. We may graphically represent this as follows:

One of the HCl molecules must contain **at least 1** atom of hydrogen and **at least 1** atom of chlorine, since fractions of atoms do not exist. But we have 2 of these HCl molecules; therefore there must be present **at least 2 atoms** of hydrogen in the hydrogen chloride formed.

Now we started with only **1 molecule** of hydrogen. Since matter can neither be created nor destroyed, we must have started with 2 atoms of hydrogen which could have been present only in the one molecule of hydrogen with which we started. In other words, **1 molecule of hydrogen** must contain at least 2 atoms of hydrogen. Actual experimentation has recently proved to us that the hydrogen molecule contains **2 and only 2** atoms of hydrogen. Irving Langmuir dissociated the hydrogen molecule at temperatures above 3000° C. and found the above theoretical conclusion to be experimentally true.

Problems

66. Experimentally, we can determine that 1 volume of nitrogen unites with 1 volume of oxygen to form 2 volumes of nitric oxide (NO). Prove that the molecule of nitrogen contains at least 2 atoms of N.

67. 1 volume of hydrogen unites with 1 volume of bromine vapor to form 2 volumes of hydrogen bromide gas (HBr). Prove that the molecule of bromine vapor contains 2 atoms of bromine.
68. 1 volume of nitrogen unites with 3 volumes of hydrogen to form 2 volumes of ammonia gas (NH_3). Prove the structure of the hydrogen molecule.
69. 3 volumes of oxygen change into 2 volumes of ozone gas when a silent electric discharge is passed through moist oxygen. Prove that the molecule of ozone contains 3 atoms of oxygen.

CHAPTER EIGHT

VAPOR DENSITY, SPECIFIC GRAVITY, WEIGHT OF A LITER. AND MOLECULAR WEIGHT OF GASES AND VAPORS

IT is often necessary to compare the relative weights of gases. Hydrogen, the lightest of gases, is used as a standard. The **vapor density** (V.D.) of a gas is the number of times that

gas is as heavy as an equal volume of **hydrogen**, both gases being weighed under standard conditions. It is really the theoretical weight of 1 cc. of the gas reduced to standard conditions.
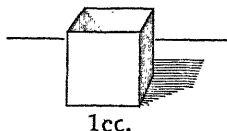
$$V.D. = \frac{\text{Weight of any volume of a gas}}{\text{Weight of an equal volume of H}}$$

If we compare the weights of a liter of each gas, then

$$V.D. = \frac{\text{Weight of 1 liter of a gas}}{\text{Weight of 1 liter of H}}$$

Since 1 liter of hydrogen weighs 0.09 gram, therefore,

$$V.D. = \frac{\text{Weight of 1 liter of a gas}}{0.09 \text{ gram}}$$

From the above we obtain

Weight of a liter of a gas $= V.D. \times .09$ gram . . (1)

Sometimes it is more convenient to compare the weight of a gas with the weight of an equal volume of air (as standard). By **specific gravity** (**Sp. Gr.**) of a gas is meant the weight of that gas as compared with the weight of an equal volume **of air**, or

$$Sp. \ Gr. = \frac{\text{Weight of any volume of a gas}}{\text{Weight of an equal volume of air}}$$

Again, let us compare the weights of 1 liter of each gas.

$$\text{Sp. Gr.} = \frac{\text{Weight of 1 liter of a gas}}{\text{Weight of 1 liter of air}}$$

Under standard conditions 1 liter of air weighs 1.293 grams; therefore,

$$\text{Sp. Gr.} = \frac{\text{Weight of 1 liter of a gas}}{1.293 \text{ grams}}$$

and from this we obtain

Weight of 1 liter of a gas = Sp. Gr. × 1.293 grams . (2)

Now let us substitute in equation (1) the weight of a liter as found in equation (2).

$$\text{Sp. Gr.} \times 1.293 = \text{V.D.} \times 0.09$$

or, since

$$\frac{1.293}{0.09} = 14.4$$

$$\text{Sp. Gr.} = \frac{\text{V.D.}}{14.4} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

PROOF THAT THE MOLECULAR WEIGHT OF A GAS IS EQUAL TO TWICE ITS VAPOR DENSITY

The atomic weight of oxygen is 16, so that its molecular weight is 32.   Hence the vapor density of oxygen is

$$\frac{\text{Weight of 1 liter of O}}{\text{Weight of 1 liter of H}} = \frac{1.43}{0.09} = 16$$

or half its molecular weight.

The weight of a liter of ammonia gas reduced to standard conditions has been found to be equal to 0.765 gram.   Its vapor density is, therefore, 8.5, or half its molecular weight of 17.   By actual experimentation it has been found that the molecular weight of **any** gas or vapor is double its vapor density, or

$$\text{Mol. Wt.} = \text{V.D.} \times 2 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

By the use of the four equations derived above we can now solve the following new type problem.

PROBLEMS OF TYPE V: TO FIND THE WEIGHT OF A LITER OF A GAS, ITS VAPOR DENSITY, SPECIFIC GRAVITY, AND MOLECULAR WEIGHT

A. EXAMPLE. 185 cc. of alcohol vapor weigh 0.24 gram. Find the weight of 1 liter of the gas, and its vapor density.

$$1 \text{ liter} = 1000 \text{ cc.}$$

Since 185 cc. weigh 0.24 gram, 1000 cc. will weigh more, or $\frac{1000}{185} \times 0.24$ grams, or 1.3 grams.

The weight of a liter of this vapor is therefore 1.3 grams. (*Place 1000 over the volume (cc.) and multiply by the weight (G).*)

Substituting in equation (1) for the weight of a liter,

$$1.3 = \text{V.D.} \times 0.09 \quad \text{or}$$
$$\text{V.D.} = \frac{1.3}{0.09} = 14.4$$

B. EXAMPLE. The vapor density of carbon monoxide is 14. Find its molecular weight, specific gravity, and the weight of 1 liter.

From equation (4)   Mol. Wt. = V.D. × 2
    Mol. Wt. = 14 × 2 = 28 = Mol. Wt. of CO

From equation (3)   Sp. Gr. $= \frac{\text{V.D.}}{14.4}$

$$\text{Sp. Gr.} = \frac{14}{14.4} = 0.97 = \text{Sp. Gr. of CO}$$

From equation (1)

Wt. of 1 liter of a gas = V.D. × 0.09
Wt. of a liter of CO = 14 × 0.09 = 1.26 grams

C. EXAMPLE. The specific gravity of ammonia gas is 0.59. Find its molecular weight, vapor density, and the weight of 325 cc. of the gas.

From equation (3)   Sp. Gr. $= \frac{\text{V.D.}}{14.4}$

$$0.59 = \frac{\text{V.D.}}{14.4} \text{ or V.D.} = 0.59(14.4)$$

V.D. of ammonia = 8.5

From equation (4)   Mol. Wt. = V.D. × 2
    Mol. Wt. of ammonia = 8.5 × 2 = 17

From equation (1)   Wt. of a liter = V.D. × 0.09

Wt. of 1 liter of ammonia = 8.5 × 0.09 = 0.765 gram

Hence the weight of 325 cc. of this gas is

$$\frac{325}{1000} \times 0.765, \text{ or } 0.249 \text{ gram}$$

$\left(\textit{Note that here we are finding the weight of a fraction of a liter, or } \dfrac{325}{1000}, \textit{ and}\right.$

$\textit{not } \dfrac{1000}{325}.\Big)$

Problems

70. 250 cc. of sulfur dioxide gas weigh 0.72 gram.   Calculate the weight of 1 liter, the molecular weight, vapor density, and specific gravity of this gas.
71. If 0.74 gram of carbon dioxide occupy 370 cc., find the weight of 1 liter, the vapor density, molecular weight, and specific gravity of this gas.
72. The molecular weight of alcohol vapor is 46.   Calculate its vapor density, specific gravity, and the weight of 1 liter.
73. The vapor density of hydrogen chloride gas is 18.25.   What is its (a) molecular weight, (b) specific gravity, and (c) the weight of 1 liter?
74. Ammonia gas has a vapor density of 8.5.   Calculate its specific gravity, molecular weight, and the weight of 167 cc. of this gas.
75. 500 cc. of phosphorus vapor weigh 2.79 grams.   Calculate (a) weight of 1 liter, (b) vapor density, (c) molecular weight, and (d) specific gravity of P vapor.
76. Sulfur trioxide vapor shows a molecular weight of 80.   Find its vapor density, specific gravity, and the weight of 9.5 liters.

D.   Example.   Find the vapor density and weight of 1 liter of chlorine gas. *Remember that the formula of chlorine gas is Cl_2 and not Cl.*

$$Cl_2$$
$$35.5 \times 2 = 71 = \text{Mol. Wt.}$$

From equation (4) $\dfrac{71}{2} = 35.5 = \text{V.D.}$

From equation (1) $35.5 \times .09 = 3.195$ g. = weight of 1 liter.

CHAPTER NINE

PROBLEMS OF TYPE VI: TO FIND THE HYDROGEN EQUIVALENT OF A METAL

THE hydrogen equivalent of a metal is that weight of the

FIG. 5. A weighed amount of metal is placed in a jar of water, and over it is placed a graduated cylinder filled with water. Acid is then added to the water in the jar. The metal reacts with the acid, liberating H_2, which is collected and measured in the graduated cylinder.

metal which will replace one gram of hydrogen, or combine with 8 grams of oxygen. It is equivalent to the atomic weight of the element divided by its valence.

The hydrogen equivalent of a metal, capable of liberating the hydrogen of an acid as the free gas, may be determined by reacting a weighed amount of the pure metal with an acid and calculating the weight of the liberated hydrogen when measured under standard conditions. (Fig. 5.)

A. EXAMPLE. Determine the equivalent of magnesium from the following data:

Weight of magnesium taken . . . . 0.0167 gram
Measured volume of H_2 gas . . . . 16.60 cc. (level of water inside and outside of measuring tube was the same)
Temperature . . . . 17° C.
Barometer reading . . . . . . 755 mm.
Aqueous tension at 17° C. . . . . 14.4 mm. (gas collected over water)

Deduct the aqueous tension of 14.4 from the total barometric pressure of 755 to get the corrected barometric pressure.

$$755 \text{ mm.} - 14.4 \text{ mm.} = 740.6 \text{ mm.}$$

Now reduce the volume of hydrogen liberated to standard conditions.

$$\frac{pv}{T} = \frac{p'v'}{T'}$$

$$\frac{740.6(16.60)}{273 + 17} = \frac{760(x)}{273}$$

$$\text{or} \quad x = \frac{740.6(16.60)273}{290(760)}$$

and $x = 15.23$ cc. of hydrogen

Under standard conditions, the weight of 1 liter of hydrogen gas is equal to 0.09 gram, or 1 gram of hydrogen will occupy 11.1 liters.

Now since 0.0167 gram of magnesium liberated 15.23 cc. of hydrogen, $0.0167 \times \frac{1000(11.1)}{15.23}$ grams of magnesium will liberate 1 gram of hydrogen. Hence $\frac{0.0167(1000)11.1}{15.23}$, or **12.16**, is the **hydrogen equivalent of magnesium.**

The formula to be used for this type of problem may be written

$$Hydrogen\ equivalent = \frac{(1000)(11.1)(wt.\ in\ grams\ of\ metal\ used)}{vol.\ in\ cc.\ (at\ stand.\ cond.)\ of\ H_2\ liberated}$$

B. EXAMPLE. 0.127 gram of a metal react with hydrochloric acid and liberate 58 cc. of hydrogen. What is the equivalent of this metal?

0.127 gram of the metal yields 58 cc. of hydrogen.

Since a liter of hydrogen weighs 0.09 gram, therefore 0.127 gram of the metal yields $\frac{58}{1000} \times 0.09$, or 0.00522 gram of hydrogen. But the equivalent of a metal will liberate 1 gram of hydrogen; hence $\frac{0.127}{0.00522}$ gram of the metal will yield 1 gram of hydrogen, or 24.3 is the equivalent of this metal.

Problems

77. Find the equivalent of aluminum from the following experimental data: 4.25 grams of the metal when heated with potash gave 5.23 liters of hydrogen measured over water at 17° C. and 760 mm., the level of the water in the eudiometer being the same as on the outside.

78. 1 gram of pure iron wire reacts with a dilute acid and the hydrogen gas evolved is collected in a eudiometer tube, over water. At 27° C. and 760 mm. the gas occupied 440 cc. What is the equivalent of iron?

79. 10 grams of tin were boiled with hydrochloric acid. When 1120 cc. of hydrogen gas were collected the action was stopped, and the tin was found to weigh 4.1 grams. What is the equivalent of tin?

80. In one of Morley's experiments on the determination of the percentage composition of water, he found that 3.265 grams of hydrogen gas united with 25.853 grams of oxygen. What is the equivalent of oxygen?

81. A gram of copper oxide was heated and hydrogen passed over it until it was completely reduced. 0.8 gram of copper was left. What is the equivalent of copper?

82. Phosphorus unites with hydrogen to form phosphine, which contains 91.2% phosphorus and 8.8% hydrogen. What is the equivalent of phosphorus?

83. Bismuth was oxidized in the presence of oxygen, yielding an oxide which on analysis showed the presence of 89.7% bismuth and 10.3% oxygen. Find the equivalent of this element.

CHAPTER TEN

PROBLEMS OF TYPE VII: TO FIND THE TRUE FORMULA OF A COMPOUND

FROM the **simplest** formula of a compound we obtain the simplest molecular weight by adding the atomic weights and placing x after this number. The **simplest** molecular weight **must** be equal to the **true** molecular weight, which gives us a means of determining the value of x. By substituting this value of x in the simplest formula, we have the **true** formula we are seeking.

A. EXAMPLE. Find the true formula of a compound which contains 63.6% nitrogen, and 36.4% oxygen, and whose **vapor density** is 21.9.

Under Type III (page 14) we found the **simplest** formula of this compound to be $(N_2O)_x$.

The **simplest** molecular weight of $(N_2O)_x$ is $(14 \times 2 + 16)x$, or $44\,x$.

By means of the **vapor density** we can find the **true** molecular weight.

$$\text{Since V.D.} = \tfrac{1}{2}\text{ Mol. Wt.}$$

therefore the **true** Mol. Wt. $= 21.9 \times 2 = 43.8$

Now the **true** Mol. Wt. is always equal to the **simplest** Mol. Wt.

$$\text{or} \quad 43.8 = 44\,x$$

from which we obtain $x = 1$ (approximately)

Substituting in the simplest formula this value of x, we find the true formula to be $(N_2O)_1$, or $\mathbf{N_2O}$.

Problems

84. A gas on analysis showed the following composition: 73.8% carbon, 8.7% hydrogen, and 17.5% nitrogen. Its vapor density was found to be 80.2. Find the true formula of this compound.

85. A compound, whose vapor density was found to be 38.8, contained carbon and hydrogen in the proportion of 92.3% and 7.7%, respectively. What is the true formula of this compound?

86. Carbon, hydrogen, and oxygen united in the ratio by weight of 39.9%, 6.7%, and 53.4%, respectively. The vapor density of the resulting compound was found to be 30.5. Determine the true formula of this compound.

87. What is the true formula of a compound containing 31.2% nickel, 3.2% hydrogen, 14.8% nitrogen, 16.9% sulfur, 33.9% oxygen, and whose molecular weight is 189?

88. The vapor density of a substance is 21.9. It contains 27.4% carbon and 72.6% oxygen. What is its true formula?

89. A compound contains twice as many hydrogen atoms as carbon atoms. Its vapor density is 14.0. Find its true formula.

90. A compound contains 24.24% carbon, 4.04% hydrogen, and 71.72% chlorine. Its vapor density is 49.6. Find its true formula.

91. The vapor density of a compound is 13.9. It consists of 85.6% carbon, and the rest of hydrogen. What is the true formula of this compound?

92. A compound contains 20.2% phosphorus, 10.4% oxygen, and 69.4% chlorine. Its vapor density is 78. Find its true formula.

93. A compound is composed of an equal weight of sulfur and oxygen. Its vapor density is 31.9. Find the true formula of this gas.

B. What is the true formula of a compound which contains 92.3% carbon and 7.7% hydrogen, and **1.1 grams of its vapor occupy 314 cc.** at standard conditions?

For carbon,

$$\frac{\% \text{ comp. of carbon}}{\text{At. Wt. of carbon}} = \frac{92.3}{12} = 7.69 \qquad \frac{7.69}{7.69} = 1 = \text{ smallest number of carbon atoms in the molecule.}$$

H.C.F. = 7.69

For hydrogen,

$$\frac{\% \text{ comp. of hydrogen}}{\text{At. Wt. of hydrogen}} = \frac{7.7}{1} = 7.7 \qquad \frac{7.7}{7.69} = 1 = \text{ smallest number of hydrogen atoms in the molecule.}$$

The simplest formula is $(CH)_x$.

The simplest Mol. Wt. is $(12 + 1)x = 13\,x$.

Since 314 cc. weigh 1.1 grams, one liter will weigh

$$\frac{1000}{314} \times 1.1, \text{ or } 3.5 \text{ grams}$$

But the weight of   1 liter = V.D. $\times$ 0.09

therefore   3.5 = V.D. $\times$ 0.09

from which we obtain   V.D. $= \frac{3.5}{.09}$, or 38.9

Hence the **true molecular weight** = V.D. $\times$ 2 = 38.9 $\times$ 2 = 77.8

$$77.8 = 13\,x$$

$$x = 6 \text{ (approximately)}$$

Therefore, the true formula is $(CH)_6$ *or* C_6H_6 *(benzene).*

We do not leave the formula as $(CH)_6$, because the molecule of this compound actually contains 6 atoms each of carbon and hydrogen.

Problems

94. One liter of a gas weighed 1.98 grams and consisted of 27.27% carbon and 72.73% oxygen. What is the true formula of this compound?

95. An oxide of sulfur was composed of 50% each of sulfur and oxygen. 2.87 grams of this gas occupied a volume of 1 liter under standard conditions. Calculate the true formula of this compound.

96. A compound showed a composition of 94.12% sulfur and 5.88% hydrogen. 100 cc. of the substance weighed 0.154 gram. What is its true formula?

97. 57 cc. of a certain gas weighed 0.134 gram. Its composition was found to be 46.15% carbon and 53.85% nitrogen. Find its true formula.

98. A compound contains 25.93% nitrogen and 74.07% oxygen. 0.097 gram of this gas occupied, under standard conditions, 20 cc. Find the true formula of this compound.

99. A compound has the following composition: carbon 37.6%, hydrogen 12.5%, and oxygen 49.9%. The weight of a liter of this vapor is 1.434 grams. What is its true formula?

100. 250 cc. of a gas weigh 0.515 gram. It contains 30.4% nitrogen and 69.6% oxygen. What is the true formula of the gas?

101. An aldehyde has the following composition: 54.7% carbon, 9.1% hydrogen, and 36.2% oxygen. If the specific gravity of its vapor is 1.526, find the true formula of the compound.

102. 500 cc. of the vapor of a compound weighed 3.1 grams. It contained 22.6% phosphorus and 77.4% chlorine. What is the true formula of this compound?

103. 0.94 gram of a compound occupies 250 cc. It contains 42% chlorine, 1.2% hydrogen, and 56.8% oxygen. Determine its true formula.

104. 500 cc. of a gas weigh 1.03 grams. It contains 30.6% nitrogen and 69.4% oxygen. What is the true formula of this compound?

CHAPTER ELEVEN

PROBLEMS BASED ON EQUATIONS

SINCE the symbol of an element and the formula of a compound represent definite weights, an equation also represents definite weights of the substances taking part in the reaction. Thus

$$2Na + S \longrightarrow Na_2S$$

may be read, " 2 atoms of sodium and 1 atom of sulfur yield 1 molecule of sodium sulfide," and it may also be read as, " 46 grams of sodium and 32 grams of sulfur yield 78 grams of sodium sulfide."

An equation is neither chemically nor mathematically correct until it is properly **balanced**, and problems based on equations cannot be solved unless those equations are balanced. Arranging the coefficients of the various substances taking part in a chemical change so that the number of atoms of each element is the same on both sides of the equation is called **balancing** the equation (see page 166). The sum of the weights on both sides of the equation must, of course, be the same. We must bear in mind that even if we had no system of writing equations, the mathematical relationship of reactions would still hold. See Appendix, pages 166–170, for exercises in balancing equations.

Problems based on chemical equations may be broadly divided into three types:

1. **Straight-Weight.** Given one weight to find another weight.

2. { *a.* **Weight-Volume.** Given a weight to find a volume.
     b. **Volume-Weight.** Given a volume to find a weight.

3. **Straight-Volume.** Given one volume to find another volume.

PROBLEMS OF TYPE VIII: STRAIGHT-WEIGHT PROBLEMS

1. Read the problem until you understand it thoroughly.
2. Obtain a balanced equation for the reaction involved. When a compound is formed from another substance by successive steps, it is not necessary to calculate the intermediate products.
3. The weight given is placed **over** the substance involved. The weight required, designated by x **grams** (or any other unit mentioned), is placed **over** the substance whose weight is to be found.
4. Since the same relationship exists between the actual weights expressed in grams, pounds, etc., as exists between the molecular weights represented by the equation, place the molecular weights of **only those substances** involved in the problem **under** those substances. Do not ignore any coefficient.
5. Check the problem again and solve for x.

A. EXAMPLE. How many grams of sodium sulfate, Na_2SO_4, are formed when 49 grams of sulfuric acid react with sodium chloride?
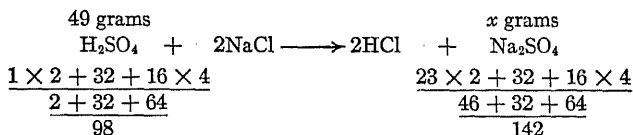
$$\begin{array}{ccccc} \overset{\text{49 grams}}{H_2SO_4} & + & 2NaCl & \longrightarrow 2HCl & + & \overset{x \text{ grams}}{Na_2SO_4} \end{array}$$

$$\frac{1 \times 2 + 32 + 16 \times 4}{\dfrac{2 + 32 + 64}{98}} \qquad\qquad \frac{23 \times 2 + 32 + 16 \times 4}{\dfrac{46 + 32 + 64}{142}}$$

$$\frac{\text{Weight of substance given}}{\text{Mol. Wt. of substance given}} = \frac{\text{Weight of substance required}}{\text{Mol. Wt. of substance required}}$$

$$\frac{49}{98} = \frac{x \text{ grams}}{142}$$

Solving for x, $98 x = 49(142)$

$$x = 71 \text{ grams } Na_2SO_4$$

Alternate method. We can avoid the use of an equation involving x by solving the above as follows:

$$\frac{\text{Weight of substance given}}{\text{Mol. Wt. of substance given}} \times \text{Mol. Wt. of substance required}$$

$$\text{or } \frac{49}{98} \times 142 = 71 \text{ grams } Na_2SO_4.$$

Problems

105. How much zinc is required to react with sufficient hydrochloric acid to produce 4 grams of hydrogen?

106. 432 grams of mercuric oxide, HgO, were completely decomposed by heat. How much mercury was formed?

107. 64 grams of oxygen were obtained by heating potassium chlorate. How much of the $KClO_3$ was used?

108. How much hydrogen would be required to reduce completely 20 grams of cupric oxide, CuO?

109. 17 grams of silver nitrate, $AgNO_3$, were required to precipitate completely all of the sodium chloride in a solution. How much NaCl was present in the solution? (Equation 6, page 99.)

110. A bottle of chlorine water was exposed to the sunlight until all the free chlorine disappeared. 20 grams of HCl gas were found. What weight of chlorine was present in the chlorine water? The equation for this reaction is $Cl_2 + H_2O \longrightarrow 2HCl + O$ (nascent oxygen).

111. What weight of magnesium will be needed to react with sulfuric acid to produce 30 grams of $MgSO_4$? What weight of hydrogen would be evolved?

112. 11.5 grams of sodium completely react with water. What weight of sodium hydroxide was produced?

113. 12 lb. of hydrogen were liberated by the electrolysis of water. What weight of water was decomposed?

B. EXAMPLE. 10 grams of crystallized copper sulfate gave, after heating, 6.4 grams of the anhydrous salt. Calculate the number of molecules of water of crystallization in the original compound.

Let x represent the number of molecules of water of crystallization.

Then
$$\underset{\text{10 g.}}{CuSO_4 \cdot xH_2O} \longrightarrow \underset{\text{6.4 g.}}{CuSO_4} + \underset{}{xH_2O}$$
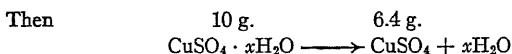
The weight of the water of crystallization is the difference between the weight of the original salt and the anhydrous salt, or, xH_2O weighs $10 - 6.4$, or 3.6 grams.

Therefore,
$$CuSO_4 \cdot xH_2O \longrightarrow \underset{\text{6.4 g.}}{CuSO_4} + \underset{\text{3.6 g.}}{xH_2O}$$

$$\frac{64 + 32 + 16 \times 4}{64 + 32 + 64} \qquad \frac{(1 \times 2 + 16)x}{(2 + 16)x}$$
$$160 \qquad\qquad\qquad 18\,x$$
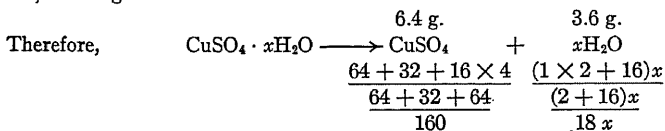
Solving for x, we obtain

$$\frac{\text{Weight of substance given}}{\text{Mol. Wt. of substance given}} = \frac{\text{Weight of substance required}}{\text{Mol. Wt. of substance required}}$$

$$\frac{6.4}{160} = \frac{3.6}{18\,x}$$

$$6.4(18\,x) = 160(3.6)$$

$$x = \frac{160(3.6)}{6.4(18)} = \frac{576}{115.2} = 5$$

$$x = 5 \text{ molecules of } H_2O$$

Problems

114. 10 grams of crystallized sodium sulfate lost 5.6 grams of water after being heated. How many molecules of water of crystallization did the original salt contain?

115. 8 grams of crystallized sodium sulfite lost 4 grams of water on being heated. How many molecules of water of crystallization did the crystalline salt contain?

116. 10 grams of crystallized washing soda after being heated gave 3.71 grams of the anhydrous Na_2CO_3. Calculate the number of molecules of water of crystallization in this compound.

117. If 2 grams of crystallized barium chloride lost 0.295 gram upon being heated to constant weight, find the formula of the crystalline salt.

118. 7 grams of crystalline calcium sulfate gave 5.536 grams of the anhydrous compound. What is the formula of the crystalline salt?

119. 11.5 grams of crystalline sodium carbonate produced 4.26 grams of the anhydrous salt. Calculate the number of molecules of water of crystallization in the original compound.

120. 10 grams of crystallized zinc sulfate gave after heating 5.62 grams of dry $ZnSO_4$. Calculate the number of molecules of water of crystallization present in the original crystalline salt.

121. 4.88 grams of anhydrous $MgSO_4$ gave 10 grams of the crystalline salt. How many molecules of water of crystallization does the crystal of magnesium sulfate contain?

CHAPTER TWELVE

PROBLEMS OF TYPE IX

I. WEIGHT-VOLUME PROBLEM
(Given a weight, to find a volume)

SINCE 0.09 gram of hydrogen occupies one liter, 2 grams of this gas will occupy 2 ÷ .09, or **22.2 liters**. Therefore the **gram-molecular volume** of hydrogen — that is, the volume occupied by its molecular weight expressed in grams — is equal to 22.2 liters (Fig. 6). A study of a large number of gases and vapors leads to the conclusion that the gram-molecular volume of all gases and vapors, when measured under standard conditions, is equal, approximately, to 22.2 liters.

Since the gram-molecular weight of a volatile substance

1.06 quarts = 1 liter

9 in.

3¾ in.

11.1 in.

GRAM-MOLECULAR VOLUME

A cube of 11.1 inches will contain 22.2 liters or 23.5 quarts.

2 grams hydrogen or 32 grams oxygen will occupy 22.2 liters.
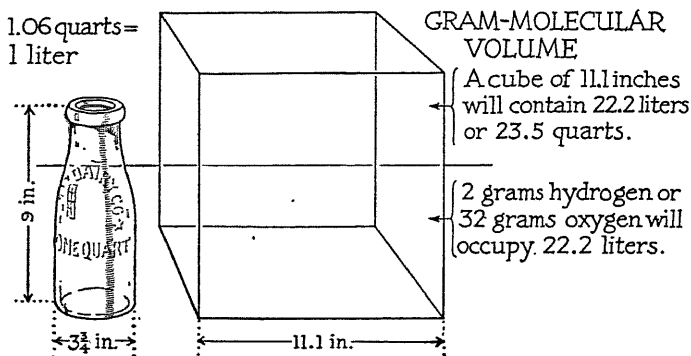
FIG. 6. Diagram showing the relative sizes of a quart bottle of milk and 22.2 liters (G.M.V.). The weight of any gas filling 23¼ of these milk bottles will be its molecular weight in grams.

occupies 22.2 liters, we can use the gram-molecular volume to represent one molecule or one volume of a gas or vapor.

The **coefficient** in front of the formula of a gas or vapor represents both the **number of molecules** and the **number of**

volumes of that gas or vapor. Thus 2CO stands for 2 molecules of carbon monoxide, $2(12 + 16)$ or 56 grams of carbon monoxide, and also for $2(22.2)$ or 44.4 liters of this gas.

In solving weight-volume problems, the same relationships hold as in the straight-weight problems, except that we may now substitute for the gram-molecular weight of the substance whose **volume** is to be determined, its gram-molecular volume, or 22.2 liters for **each volume** of that substance.

EXAMPLE. How many liters of carbon dioxide gas can be prepared from 500 grams of calcium carbonate?

$$\begin{array}{ccc} 500 \text{ g.} & & x \text{ liters} \\ CaCO_3 & \longrightarrow \quad CaO \quad + & CO_2 \\ \dfrac{40 + 12 + 48}{100} & & \dfrac{1(22.2)}{22.2} \end{array}$$
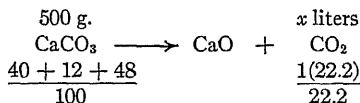
$$\frac{\text{Weight of substance given}}{\text{Mol. Wt. of substance given}} = \frac{\text{Volume of substance required}}{\text{Volume of substance required (Gram-Mol. Vol.)}}$$

$$\frac{500}{100} = \frac{x \text{ liters}}{22.2}$$

$$x = 111 \text{ liters of } CO_2$$

Alternate method. (Avoiding the use of x.)

$$\text{Vol. of } CO_2 = \frac{\text{Weight of substance given}}{\text{Mol. Wt. of substance given}} \times \text{Gram-Mol. Vol.}$$

$$\text{Vol. of } CO_2 = \frac{500}{100} \times 22.2 = 111 \text{ liters}$$

NOTE. By a coincidence, the same relation exists between the **gram**-molecular weight and the **gram**-molecular volume — that is, **22.2 liters** — as exists between the **ounce**-molecular weight and the **ounce**-molecular volume; namely **22.2 cu. ft.** This coincidence occurs because

$$\begin{array}{l} 1 \text{ ounce} = 28.3 \text{ grams and} \\ 1 \text{ cu. ft.} = 28.3 \text{ liters.} \end{array}$$

Remember that **grams** correspond to **liters**, and **ounces** correspond to **cubic feet.** For other units of weight and volume, conversion factors must be used.

Problems

122. What volume of hydrogen can be obtained by the electrolysis of 90 grams of water?
123. A lump of carbon weighing 24 grams was burned in oxygen. What volume of carbon dioxide was formed?
124. How many liters of hydrogen sulfide gas can be obtained by the action of an acid on 11 grams of ferrous sulfide, FeS? (Eq. 1, p. 103.)
125. 216 ounces of magnesium will be needed to react with sufficient hydrochloric acid to liberate what volume of hydrogen?
126. How many liters of ammonia gas can be formed by the action of 66 grams of ammonium sulfate on slaked lime, $Ca(OH)_2$? (Eq. 1, p. 107.)
127. What volume of sulfur dioxide gas will be liberated when 32 grams of copper are completely dissolved by concentrated sulfuric acid? (Eq. 6, p. 105.)
128. How many liters of carbon dioxide gas, measured under standard conditions, can be obtained by the action of 49 grams of sulfuric acid on marble? $CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + H_2O + CO_2$.
129. What volume of hydrogen is needed to reduce completely 24 grams of copper oxide, CuO, to pure copper?

II. VOLUME-WEIGHT PROBLEM
(Given a volume, to find a weight)

The same procedure is followed as in the previous example until the equation involving x is to be written.

EXAMPLE. What weight of potassium chlorate will be needed to obtain 11.1 liters of oxygen?

$$\begin{array}{cc} x \text{ grams} & 11.1 \text{ liters} \\ 2KClO_3 & \longrightarrow \quad 3O_2 \quad + 2KCl \\ \dfrac{2(39 + 35.5 + 48)}{245} & \dfrac{3(22.2)}{66.6} \end{array}$$

$$\frac{\text{Volume of the substance given}}{\text{Gram-Mol. Vol. of substance given}} = \frac{\text{Weight of substance required}}{\text{Mol. Wt. of substance required}}$$

$$\frac{11.1}{66.6} = \frac{x \text{ grams}}{245}$$

$$(11.1)245 = 66.6 \, x$$

$$x = 40.8 \text{ grams } KClO_3$$

Alternate method. (Avoiding the use of x.)

$$\text{Wt. } KClO_3 = \frac{\text{Volume of substance given}}{\text{Gram-Mol. Vol. of substance given}} \times \begin{array}{c}\text{Mol. Wt. of substance} \\ \text{required}\end{array}$$

$$= \frac{11.1}{66.6} \times 245 = 40.8 \text{ grams}$$

Problems

130. What weight of zinc will be required to produce 44.4 liters of hydrogen gas?

131. How many grams of calcium carbonate will have to be treated with sulfuric acid to produce 5.55 liters of carbon dioxide? (See Problem 128.)

132. How many grams of FeS will be needed to prepare 88.8 liters of hydrogen sulfide gas? (Equation 1, page 103.)

133. What weight of pure carbon will have to be burned to produce 44.4 cc. of carbon dioxide?

134. What weight of the carbon would be needed to prepare the same volume of carbon monoxide?

135. What weight of phosphorus will have to be burned completely to remove all the oxygen in 10 liters of air, assuming that air contains 20% of oxygen by volume? $4P + 3O_2 \longrightarrow 2P_2O_3$.

136. What weight of copper must be dissolved by concentrated sulfuric acid to produce 99.9 cc. of sulfur dioxide gas? (Equation 6, page 105.)

137. What weight of sodium must be used to produce 1 liter of hydrogen gas measured at standard conditions?

138. How much sodium chloride will be needed to produce 111 liters of hydrogen chloride gas? $NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$.

139. What weight of sulfur will have to be burned to produce 50 cc. of sulfur dioxide gas?

140. What weight of water must be decomposed to furnish enough oxygen to form, with pure carbon, 44.4 liters of carbon dioxide?

CHAPTER THIRTEEN

PROBLEMS OF TYPE X: STRAIGHT–VOLUME PROBLEM
(*Given one volume, to find another volume*)

FROM Avogadro's Law we may conclude that the coefficients of formulas representing gases or volatile compounds **also** represent their volumes. Therefore the same relationship exists between the gram-molecular weights of gases, their gram-molecular volumes, and their coefficients.

In the solution of problems involving only the volumes of gases or volatile substances, we need consider only their volumes or coefficients. We form our equations accordingly.

A. EXAMPLE. How many liters of carbon dioxide will be formed in the complete combustion of 12 liters of benzene?

$$\begin{array}{ccccccc}
12 \text{ liters} & & & & & & x \text{ liters} \\
2C_6H_6 & + & 15O_2 & \longrightarrow & 6H_2O & + & 12CO_2 \\
2 \text{ vol.} & & & & & & 12 \text{ vol.}
\end{array}$$

$$\frac{\text{Volume of substance given}}{\text{Coefficient of substance given}} = \frac{\text{Volume of substance required}}{\text{Coefficient of substance required}}$$

$$\frac{12}{2} = \frac{x}{12}$$

$$144 = 2x$$

$$x = 72 \text{ liters of } CO_2$$

Alternate method (avoiding the use of x).

Volume $CO_2 = \dfrac{\text{Volume of substance given}}{\text{Coefficient of substance given}} \times$ coefficient of substance

required $= \dfrac{12}{2} \times 12 = 72$ liters of CO_2

B. EXAMPLE. What volume of **air** (containing 20% oxygen by volume) would be required to burn completely 352 cc. of carbon monoxide?

$$\begin{array}{ccccc}
352 \text{ cc.} & & x \text{ cc.} & & \\
2CO & + & O_2 & \longrightarrow & 2CO_2 \\
2 & & 1 & &
\end{array}$$

$$\frac{352}{2} = \frac{x}{1} \text{ or } x = 176 \text{ cc. of } \textbf{oxygen}$$

But, since the air contains only 20% oxygen by volume, the volume of air required in the above reaction will be 5 times that of oxygen, or $5 \times 176 = 880$ cc. **air.**

Problems

141. What volume of hydrogen must unite with 2 liters of oxygen to form water and leave no oxygen over?
142. If 20 liters of hydrogen react with sufficient chlorine, what volume of hydrogen chloride gas will be formed?
143. How many liters of its component gases can be obtained by the complete decomposition of 6 liters of ammonia gas? $2NH_3 \longrightarrow N_2 + 3H_2$.
144. Carbon monoxide passed over warm calcium hydroxide reacts according to the equation $CO + Ca(OH)_2 \longrightarrow CaCO_3 + H_2$. How does the volume of carbon monoxide compare with that of hydrogen?
145. How many cubic centimeters of oxygen will be needed to produce 55 cc. of sulfur dioxide gas?
146. What volume of air will convert 100 cc. of nitric oxide, NO, into nitrogen peroxide, NO_2?
147. How many liters of air are necessary for the complete combustion of 500 cc. of acetylene gas? $2C_2H_2 + 5O_2 \longrightarrow 4CO_2 + 2H_2O$.
148. How many cubic feet of air will be used in the complete combustion of 750 cu. ft. of methane, CH_4? $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$.

CHAPTER FOURTEEN

MISCELLANEOUS PROBLEMS

I. PROBLEMS INVOLVING AN EXCESS OF ONE OR MORE REAGENTS

THIS group of problems is really not a new type but is one which involves the previous type problems in one form or another. We know that substances unite chemically according to definite weights. Therefore if we mix chemicals regardless of these definite weights, and a chemical reaction takes place, a part of one or more of the reagents will be left over after the reaction is completed. We cannot, by inspection, tell which substance is in excess.

EXAMPLE. A mixture of 35 cc. of oxygen and 50 cc. of hydrogen is exploded. How much water vapor is formed, and what is the nature and volume of the gas which has not taken part in the action?

$$\begin{array}{ccc} 50 \text{ cc.} & 35 \text{ cc.} & x \text{ cc.} \\ 2H_2 + & O_2 & \longrightarrow 2H_2O \\ 2 & 1 & 2 \end{array}$$
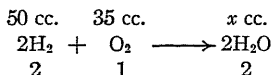
50 cc. of hydrogen would require $\frac{50}{2} \times 1$, or 25 cc. of oxygen.

35 cc. of oxygen would require $\frac{35}{1} \times 2$, or 70 cc. of hydrogen.

But only 50 cc. of hydrogen are available, therefore some of the oxygen will be left over. Since only 25 cc. of oxygen would be required to react with all of the hydrogen available, $35 - 25$, or **10 cc. of oxygen would remain.**

Problems

149. 100 cc. of chlorine and 200 cc. of hydrogen are mixed and made to unite chemically. What volume of hydrogen chloride gas was formed, and how much gas remained unacted upon?

150. When 14 cc. of sulfur vapor and 10 cc. of oxygen combine as far as possible to form sulfur dioxide, what volume of SO_2 is formed, and how much of either factor is left?

151. 4 grams of carbon and 9 liters of oxygen are combined chemically as far as possible. How much oxygen remains uncombined?

152. 4.8 grams of magnesium ribbon were made to react with 2 liters of chlorine gas until no further reaction could take place. What weight of magnesium chloride was formed, and how much of either factor remained?

153. 100 grams of mercury and 11.1 liters of oxygen reacted chemically until no further union could take place. How much mercuric oxide was formed, and what weight of either substance remained uncombined?

154. 234 grams of sodium chloride and 294 grams of sulfuric acid were used to make hydrochloric acid. What weight of hydrogen chloride gas was liberated?

155. 17 grams of silver nitrate in solution were added to a solution containing 2.34 grams of sodium chloride. What weight of silver chloride precipitated out?

156. What weight of barium sulfate was precipitated when 104 grams of $BaCl_2$ reacted with a solution containing 35.5 grams of Na_2SO_4?

II. PROBLEMS INVOLVING THE MOST ECONOMICAL CHEMICALS TO USE

A. EXAMPLE. Which would be cheaper, neutralizing 50 lb. of sulfuric acid with commercial caustic potash (containing 10% water) and costing $7\frac{1}{8}\cent$ per pound, or neutralizing it with caustic soda (containing 76% NaOH) and costing $3.10 per 100 lb.? How much cheaper would it be?

The equation for the reaction using caustic soda is

$$\begin{array}{ccc} x \text{ lb.} & 50 \text{ lb.} & \\ 2NaOH & + & H_2SO_4 & \longrightarrow Na_2SO_4 + 2H_2O \\ \dfrac{2(23 + 16 + 1)}{80} & \dfrac{2 + 32 + 64}{98} & \end{array}$$
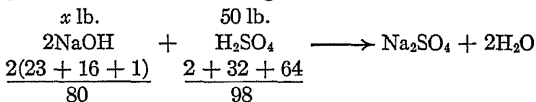
The weight of **pure NaOH** $= \dfrac{50}{98} \times 80 = 40.8$ lb.

Since the NaOH is only 76% pure, we will need more of the commercial NaOH. The cost of this commercial NaOH will be

$$\dfrac{\$3.10}{100} \times 40.8 \times \dfrac{100}{76} = \$1.66$$

The equation for the reaction using caustic potash is

$$\begin{array}{ccc} x \text{ lb.} & 50 \text{ lb.} & \\ 2KOH & + & H_2SO_4 & \longrightarrow K_2SO_4 + 2H_2O \\ \dfrac{2(39 + 16 + 1)}{112} & \dfrac{2 + 32 + 64}{98} & \end{array}$$
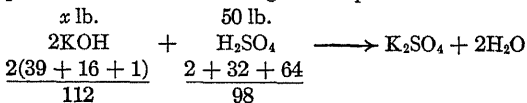
The weight of pure KOH needed would be

$$\frac{50}{98} \times 112 = 57.1 \text{ lb.}$$

The cost of this KOH would be (since commercial KOH is 90% pure)

$$7\tfrac{1}{8}¢ \times 57.1 \times \frac{100}{90}, \text{ or } \$4.52$$

Hence it would cost \$4.52 minus \$1.66, or \$2.86 more if the commercial caustic potash were used.

Problems

157. Which is the more economical to use in the preparation of ammonia, ammonium sulfate at \$8.75 per 100 lb. or ammonium chloride at 12 cents per pound?

158. We can buy potassium chlorate at 7¢ per pound or sodium chlorate at $6\tfrac{1}{2}$¢ per pound. Which is the more economical oxidizing agent?

159. Which would be cheaper for preparing carbon dioxide, calcium carbonate at 1¢ a pound, or sodium bicarbonate at \$2 per 100 lb.?

160. Would it be more economical to buy sodium peroxide (costing 9¢ per pound), or to make it from metallic sodium costing 27¢ per pound?

161. How much money could be saved by using either sulfuric acid at \$1.35 per 100 lb., or 50% nitric acid costing \$5 per 100 lb., to neutralize a solution containing 2000 lb. of NaOH?

162. How much of a saving would be involved in using either bromine (47¢ per pound), or chlorine (6¢ per pound) in an oxidation process requiring 7.1 tons of chlorine, assuming that either one could just as well be used?

III. CALCULATIONS OF MIXTURES HAVING A COMMON CONSTITUENT

EXAMPLE. A mixture of AgCl and AgI weighs 2.5 grams. The weight of silver is 1.5 grams. Find the weight of AgCl and of AgI.

$$\text{Let } x = \text{weight of AgCl}$$
$$\text{Let } y = \text{weight of AgI}$$
$$\text{Then } x + y = 2.5 \text{ grams} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The weight of Ag in AgCl $= \dfrac{\text{At. Wt. of Ag}}{\text{Mol. Wt. of AgCl}} \, x = \dfrac{108}{143.5} \, x$

The weight of Ag in AgI $\; = \dfrac{\text{At. Wt. of Ag}}{\text{Mol. Wt. of AgI}} \, y = \dfrac{108}{235} \, y$

The total weight of the silver in the mixture is 1.5 grams, therefore,

$$\frac{108}{143.5} \, x + \frac{108}{235} \, y = 1.5 \text{ grams} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Substituting in (2) the value of y found in (1), we obtain

$$\frac{108}{143.5} x + \frac{108}{235} (2.5 - x) = 1.5 \text{ grams}$$
$$0.753 x + 0.46(2.5 - x) = 1.5$$
$$0.753 x + 1.15 - 0.46 x = 1.5$$
$$0.293 x = 1.5 - 1.15$$
$$x = 1.2 \text{ grams of ÁgCl}$$
$$y = 1.3 \text{ grams of AgI}$$

Problems

163. Given a mixture of KCl and NaCl weighing 5 grams and containing 60% chlorine. Calculate the weights of KCl and NaCl in the mixture.

164. The weight of a mixture of silver chloride and silver bromide is 6 grams. On analysis 4.5 grams of pure silver were found in the mixture. What weights of AgCl and AgBr were present in the mixture?

165. 0.5 gram of a mixture of potassium iodide and potassium bromide yielded 0.3 gram of K_2SO_4. How much KBr and KI were present in the mixture?

166. A mixture of K_2SO_4 and Na_2SO_4 weighed 1.43 grams. From this mixture 2.136 grams of $BaSO_4$ were obtained. Find the weights of potassium and sodium sulfate present in the original mixture.

167. 2.144 grams of a mixture of calcium and strontium carbonates gave 2.844 grams of a mixture of calcium and strontium sulfates. What weights of $CaCO_3$ and $SrCO_3$ were present in the mixture?

168. If 8 grams of dolomite ($CaCO_3 \cdot MgCO_3$) liberated 3.8 grams of carbon dioxide gas, what was the percentage of calcium and magnesium in this sample of dolomite?

169. A mixture of K_2CO_3 and $KHCO_3$ weighs 2 grams and contains 0.8 gram of CO_2. What is the weight of each constituent in the mixture?

170. A mixture of $PbSO_4$ and $BaSO_4$ weighed 1 gram, and an analysis showed the presence of 0.405 gram of the SO_4 radical. What weights of the two sulfates were present in the mixture?

CHAPTER FIFTEEN

CHEMICAL PROBLEMS FROM NEW YORK STATE REGENTS EXAMINATION PAPERS

January, 1915

171. Find the number of liters of carbon dioxide that will result from the addition of sufficient hydrochloric acid to 100 grams of calcium carbonate. [10] (Atomic weights: C = 12, O = 16, Cl = 35.5, Ca = 40)

172. Find the number of volumes of hydrogen and of nitrogen that enter into combination to form 200 liters of ammonia. [10]

June, 1915

173. How many liters of hydrogen sulfide are obtained by adding sufficient hydrochloric acid to 88 grams of ferrous sulfide? [10] (Atomic weights: Fe = 56, S = 32)

174. Find the cost of enough potassium chlorate at 80 cents per kilogram to make 800 liters of oxygen. [10] (Atomic weights: K = 39, Cl = 35.5, O = 16)

January, 1916

175. Find the number of liters of hydrogen sulfide that will result from the addition of sufficient hydrochloric acid to 100 grams of ferrous sulfide. [10] (Atomic weights: S = 32, Fe = 55.8)

176. Show what will be the relative volumes of the reacting substances in each of the following cases: (*a*) one volume of carbon monoxide plus sufficient oxygen burns to carbon dioxide [4], (*b*) one volume of marsh gas plus sufficient oxygen burns to carbon dioxide and water [6].

June, 1916

177. Find the number of liters of ammonia gas that may be prepared from 107 grams of ammonium chloride and sufficient slaked lime. [10] (Atomic weights: N = 14, Cl = 35.5)

178. If a sample of gasoline is half hexane, C_6H_{14}, and half heptane, C_7H_{16}, how many cubic feet of air will be necessary for the complete combustion of 100 cubic feet of gasoline vapor? [10] (Assume air as one-fifth oxygen by volume.)

January, 1917

179. What will a liter of oxygen weigh at 740 mm. pressure and 20° C., if it weighs 1.43 grams under standard conditions? [10]
180. Find the cost of making 100 liters of hydrogen sulfide, given the following data (wholesale prices): sulfur 3¢ a kilogram, scrap iron 15¢ a kilogram, concentrated (assume 100%) sulfuric acid 2¢ a kilogram. [10] (Atomic weights: S = 32, Fe = 55.5)
181. How many liters of carbon dioxide will result from the complete combustion of 10 liters of carbon monoxide [5]? Find the weight of copper precipitated from its sulfate solution by 10 grams of iron [5]. (Atomic weights: Fe = 55.5, Cu = 63.6)

June, 1917

182. There are five molecules of water in each molecule of crystallized copper sulfate; find the number of grams of water required to crystallize 100 grams of anhydrous copper sulfate. [10] (Atomic weights: O = 16, S = 32, Cu = 63.6)
183. How many liters of carbon dioxide gas will be formed by the fermentation of 180 grams of grape sugar according to the following equation: $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$? [10] (Atomic weights: O = 16, C = 12)

January, 1918

184. Find the number of liters of oxygen gas measured under standard conditions produced by the decomposition of 245 grams of potassium chlorate. [10] (Atomic weights: K = 39, Cl = 35.5, O = 16)
185. What will a liter of carbon dioxide weigh at 750 mm. pressure and 20° C. temperature, if it weighs 1.98 grams at 776 mm. pressure and 0° C. temperature? [10]

June, 1918

186. Name a gas composed of two elements, which, when burned in air or oxygen, forms water and sulfur dioxide [3]. How many liters of oxygen are required for the complete combustion of five liters of this gas [7]?

187. Find the weights and the volumes of oxygen and hydrogen forming 180 grams of water. [10] (Atomic weight: $O = 16$)

188. Find the weight of ammonium sulfate necessary, when heated with the required amount of slaked lime, to make two liters of ammonia water, allowing 700 volumes of ammonia gas to one volume of water for full-strength solution. [10] (Atomic weights: $S = 32$, $N = 14$)

January, 1919

189. Find the number of grams of copper needed to prepare 10 liters of nitric oxide by interaction with moderately dilute nitric acid. [10] (Atomic weights: $O = 16$, $Cu = 63.6$, $N = 14$)

190. Find the percentage of copper in bluestone, $CuSO_4 \cdot 5H_2O$. [10] (Atomic weights: $O = 16$, $Cu = 63.6$, $S = 32$)

191. If 5 grams of hydrated barium chloride, heated to constant weight, weigh 4.265 grams, find (*a*) the percentage of water in the crystals [5]; (*b*) the number of molecules of water of crystallization per molecule of barium chloride [5]. (Atomic weights: $O = 16$, $Ba = 137$, $Cl = 35.5$)

June, 1919

192. What weight of ammonia could be obtained (theoretically) by heating 100 pounds of ammonium sulfate with an excess of slaked lime [7]? What volume would it occupy [3]? (Atomic weights: $N = 14$, $S = 32$, $O = 16$. 1 cu. ft. of ammonia weighs .048 lb.)

193. What volume of oxygen would be required for the complete combustion of 1000 cubic feet of acetylene? [10]

194. A certain gas consists of 14.29% of hydrogen in combination with 85.71% of carbon.   Measured at standard conditions, 50 cubic centimeters of the gas weighs .063 gram.   Calculate the chemical formula of the gas.   [10]   (Atomic weight: $C = 12$)

January, 1920

195. A gas is found by analysis to contain 46.15% of carbon and 53.85% of nitrogen; 57 cc. of this gas, reduced to standard conditions, weighs .1334 gram.   From the above data derive the chemical formula of the gas.   [10]   (Atomic weights: $C = 12, N = 14$)

196. What weight of iron could be obtained theoretically from 200 tons of ore containing 85% ferric oxide?   [10]   (Atomic weights: $Fe = 56, O = 16$)

June, 1920

197. What weight of sodium chloride will precipitate all the silver from a solution made by dissolving 1 gram of silver in nitric acid?   [10]   (Atomic weights: $Na = 23, Cl = 35.5, Ag = 108, N = 14, O = 16$)

198. How many liters of hydrogen chloride at standard conditions will be necessary to neutralize a water solution of 10 grams of sodium hydroxide?   [10]   (Atomic weights: $Cl = 35.5, Na = 23, O = 16$)

199. Assuming air to contain 20 per cent of oxygen, state how many cubic feet of air would be required for the complete combustion of 1000 cubic feet of acetylene.   [10]

January, 1921

200. Calculate the weight of barium chloride which, reacting with sufficient sulfuric acid, yields 1.46 grams of barium sulfate. [10]   (Atomic weights: $Ba = 137, Cl = 35.6, S = 32, O = 16$)

201. How many liters of chlorine (standard conditions) are required to liberate 40 grams of bromine from a solution of potassium bromide?   [10]   (Atomic weights: $Br = 80, K = 39, Cl = 35.6$)

202. Find the volume of methane whose complete combustion forms 10 cubic feet of carbon dioxide. [10] (Atomic weights: C = 12, O = 16)

June, 1921

203. In the following equation, if 20 grams of Chile saltpeter are used, state what weight of potassium nitrate will be found: $NaNO_3 + KCl = KNO_3 + NaCl$ [10] (Atomic weights: K = 39, Cl = 35.5, Na = 23, O = 16, N = 14)
204. Magnesium acting with an acid liberates 100 cc. of hydrogen measured at 22° C. and 780 mm. pressure. Calculate (*a*) the volume of this hydrogen measured at standard conditions [5], (*b*) the weight of the magnesium needed [5]. (Use .09 as the weight of one liter of hydrogen at standard conditions and 24 as the atomic weight of magnesium.)
205. From 1 gram of pure iron 1.43 grams of an oxide of iron are formed; find (*a*) the percentage composition of the oxide [5], (*b*) the simplest formula of the oxide [5]. (Atomic weights: Fe = 56, O = 16)

January, 1922

206. Baking soda and cream of tartar in baking powder react as follows: $NaHCO_3 + KHC_4H_4O_6 = NaKC_4H_4O_6 + H_2O + CO_2$. How much baking soda is required for 47 grams of cream of tartar [5]? What volume of CO_2 will this free [5]? (Atomic weights: Na = 23, C = 12, O = 16, K = 39)
207. Name the gases formed and compute their volumes when 10 liters of methane completely unite with oxygen. [10] (Measurements at standard conditions. Atomic weights: C = 12, O = 16)
208. If 4.265 grams of anhydrous barium chloride weigh 5 grams when hydrated, find (*a*) the percentage of water of crystallization [5], (*b*) the number of molecules of water of crystallization to one molecule of barium chloride [5]. (Atomic weights: Ba = 137, Cl = 35.5, O = 16)

June, 1922

209. If 126 grams of copper react with an excess of nitric acid according to the equation $3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 4H_2O + 2NO$, calculate (*a*) the weight of copper nitrate formed [5], (*b*) the volume of nitric oxide formed [5]. (Atomic weights: Cu = 63.6, O = 16, N = 14)

210. The weight of 500 cc. of a gas is 0.76 grams; calculate (*a*) the molecular weight [5], (*b*) the vapor density [5].

211. Given the equation $2CO + O_2 = 2CO_2$; state (*a*) the chemical change indicated [2], (*b*) the number of atoms in each molecule [2], (*c*) the number of molecules [2], (*d*) the relative volumes [2], (*e*) the parts by weight [2]. (Atomic weights: C = 12, O = 16)

January, 1923

212. If 106 grams of ammonium chloride react with an excess of sodium hydroxide, calculate (*a*) the number of grams of ammonia formed [5], (*b*) the number of liters of ammonia formed, measured under standard conditions [5]. (Atomic weights: N = 14, Cl = 35.5)

213. What volume of methane measured under standard conditions can be burned to carbon dioxide and water in 50 liters of oxygen similarly measured? [10]

214. Calculate the volume of 915 cc. of hydrogen at 27° C. and 760 mm. when changed to standard conditions [5]. What is the equivalent of magnesium if $\frac{9}{10}$ of a gram of this metal liberates the hydrogen mentioned in the first part of this question [5]?

June, 1923

215. Calculate the weight of $KClO_3$ required to produce 20 liters of oxygen. [10] (Atomic weights: K = 39, Cl = 35.5, O = 16)

216. Find the volume of oxygen necessary for the complete oxidation of 100 cubic feet of water gas containing by volume 40% carbon monoxide and 60% hydrogen. [10]

217. The molecular formula of a certain gas is C_2N_2; calculate (*a*) the molecular weight [2], (*b*) the vapor density [2], (*c*) the specific gravity (air standard) [2], (*d*) the weight of one liter [2], (*e*) the percentage composition by weight [2]. (Atomic weights: C = 12, N = 14)

218. The percentage composition of a substance is C 39.95%, H 6.69%, O 53.36%. Deduce its formula. [10] (100 cu. cm. of its vapor at standard conditions weighs .134 gram. Atomic weights: C = 12, O = 16)

January, 1924

219. Magnesium dissolved in acid gave 100 cc. of hydrogen at a temperature of 22° C. and a pressure of 780 mm.; how many grams of metal were used? (Atomic weight: Mg = 24.3) [10]

220. Calculate the percentage of nitrogen in crystallized copper nitrate, $Cu(NO_3)_2 \cdot 6H_2O$ [5]. There are five molecules of water in each molecule of crystallized copper sulfate; how many grams of water unite with 100 grams of anhydrous copper sulfate to produce crystallized copper sulfate [5]? (Atomic weights: O = 16, N = 14, S = 32, Cu = 63.5)

221. Find the weight of a liter of (*a*) chlorine [3], (*b*) methane [3]. Calculate the number of liters of carbon dioxide formed in the complete combustion of 100 liters of acetylene [4]. (Atomic weights: Cl = 35.5, O = 16, C = 12)

June, 1924

222. If 54 grams of silver react with an excess of nitric acid according to the equation $3Ag + 4HNO_3 = 3AgNO_3 + 2H_2O + NO$, what weight of silver nitrate and what volume of nitric oxide measured under standard conditions of temperature and pressure will be formed? [10] (Atomic weights: Ag = 108, O = 16, N = 14)

223. Calculate the molecular weight of a gas 50 cc. of which weigh .067 gram. Assuming that 46.6% of it by weight is nitrogen and the rest oxygen, calculate the chemical formula. [10] (Atomic weights: N = 14, O = 16)

224. How many liters of hydrogen are needed to convert 30 liters of nitrogen into ammonia? [10]

January, 1925

225. A certain solution contains .049 gram of sulfuric acid in each cubic centimeter. How many cubic centimeters of this solution would be needed to neutralize 100 cc. of a solution of sodium hydroxide which contains .04 gram per cubic centimeter? [10]

226. What weight of calcium oxide could be obtained from 200 grams of pure calcium carbonate [6]? What volume of carbon dioxide measured at standard conditions would be liberated in the reaction [4]?

227. Name the important experimental operations that are carried out in determining the chemical formula of a newly discovered substance, assuming that it can readily be converted into the gaseous state [4]. Illustrate the process by calculating data which should be approximated in actual operations carried out to verify the formula of ethane, C_2H_6 [6].

June, 1925

228. Calculate the weight of ammonia that can be obtained from 200 grams of ammonium chloride. What volume will this occupy at standard conditions? [10]

229. Find the weight of a liter of chlorine [4]. Calculate the number of liters of carbon dioxide formed by the complete combustion of 200 liters of acetylene [6].

230. A student on analyzing two different oxides of iron obtained the following results: in the first he found 8 parts by weight of oxygen combined with 28 of iron, in the second 5.5 parts of oxygen with 14 parts of iron. Show that these results are probably wrong because they do not agree with one of the important laws of chemistry. [10]

PART TWO

CHAPTER SIXTEEN

TO FIND THE MOLECULAR WEIGHTS OF GASES AND VOLATILE COMPOUNDS

THE molecular weights of gases or volatile compounds can be determined by means of the equations derived in the study of the vapor density of gases.

If we combine equations (1) and (4) (pages 28 and 29); namely,

Wt. of 1 liter of a gas = V.D. × 0.09

and Mol. Wt. = V.D. × 2,

we obtain Mol. Wt. = $\dfrac{\text{Wt. of a liter of a gas} \times 2}{0.09}$

or Mol. Wt. = Wt. of 1 liter × 22.2 $\left(\text{since } \dfrac{2}{0.09} = 22.2\right)$

In other words, the molecular weight of a gas is equal to the weight of 22.2 liters of that gas. Since it is inconvenient to work with 22.2 liters, a smaller volume is weighed and the weight of 22.2 liters is determined from the experimental data. The most common methods in use are the Dumas, and Victor Meyer methods.

Dumas method. A globe of measured volume (Fig. 7) is filled with the gas or vapor, sealed, and then weighed. It is then completely exhausted by means of an air pump, again sealed, and the weight of the evacuated bulb determined. The difference in weight is, of course, the weight of the gas or vapor. From these data the weight of 22.2 liters is determined.

EXAMPLE. A globe of 500 cc. capacity was filled with carbon monoxide gas under standard conditions. When filled it weighed 325.73 grams. When evacuated the globe weighed 325.10 grams. Calculate the molecular weight of this gas.
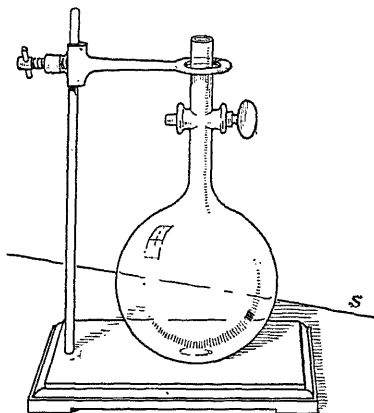
FIG. 7. A Dumas bulb of measured capacity.

The weight of the 500 cc. of the gas = 325.73 − 325.10 = 0.63 gram

Therefore, the weight of 1 liter $= \dfrac{1000}{500} \times 0.63 = 1.26$ grams

The weight of 22.2 liters, then, $= 1.26 \times 22.2 = 27.97$ grams

Hence the molecular weight of the gas is 27.97.

Victor Meyer method. A weighed amount of liquid is vaporized, and the air which this vapor displaces is measured (Fig. 8). This volume is corrected to standard conditions, and from these data the weight of the liquid, which when vaporized occupies 22.2 liters, is determined. This, of course, corresponds to the molecular weight of the gas. This method is just the reverse of the Dumas method. It is applicable, not to gases, but to liquids which volatilize without decomposition.

EXAMPLE. 0.755 gram of carbon disulfide displaced, when vaporized, 221cc. of air under standard conditions. Determine its molecular weight.

221 cc. were displaced by 0.755 grams

1000 cc. would be displaced by $0.755 \times \dfrac{1000}{221}$ grams

22.2 liters would be displaced by $0.755 \times \dfrac{1000}{221} \times 22.2$ grams

The molecular weight of carbon bisulfide is, therefore,

$$\frac{0.755(1000)22.2}{221} = 76$$
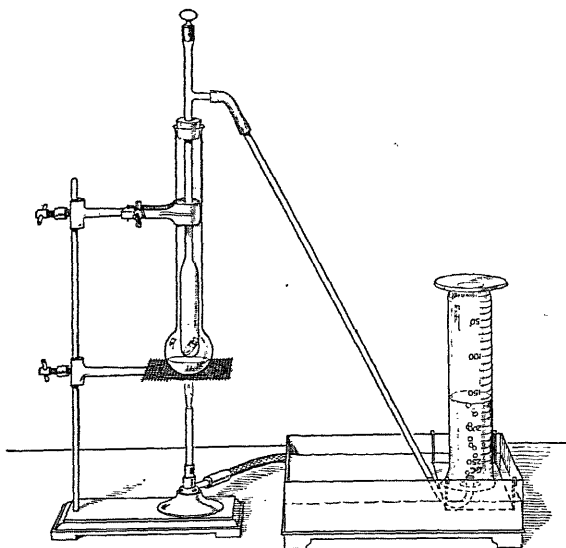
FIG. 8. In this Victor Meyer apparatus a weighed amount of liquid in the small vial is vaporized. The vapor displaces its own volume of air found in the apparatus. This air, in turn, displaces its volume of water in the graduated cylinder. The volume of water displaced corresponds to the volume of the vapor of the liquid whose molecular weight is to be determined.

The formula to be used for this type of problem may be written

$$Mol.\ Wt. = \frac{(1000)(22.2)(weight\ in\ grams\ of\ substance\ vaporized)}{volume\ in\ cc.\ (at\ stand.\ cond.)\ of\ displaced\ air}$$

Problems

1. Calculate the molecular weight of carbon tetrachloride, CCl₄, from the following data:

Weight of CCl_4 taken . . . . 0.62 gram
Volume of air displaced . . . . . 88.8 cc.
Temperature of air measured . . . . 0° C.
Barometric pressure . . . . 760 mm.

2. Calculate the vapor density of carbon bisulfide from the following data:

Weight of CS_2 taken . . . . . . 0.152 gram
Volume of air displaced . . . . . 44.4 cc.
Temperature of air measured . . . . 0° C.
Barometer reading . . . . 760 mm.

3. A Dumas bulb of 250 cc. capacity was filled with acetylene gas. Calculate the molecular weight of the gas from the following data:

Weight of bulb plus acetylene gas . . . 253.480 grams
Weight of evacuated bulb . . . . . 253.187 grams
Temperature of experiment . . . . . 27° C.
Barometer reading . . . . 760 mm.

4. Calculate the molecular weight of chloroform from the following:

Weight of bulb plus chloroform vapor . 36.02 grams
Weight of evacuated bulb . . . . . 34.34 grams
Temperature of experiment . . . . . 67° C.
Barometer reading . . . . 760 mm.
The Dumas bulb had a capacity of . . 400 cc.

5. Find the molecular weight of iodine from the following data obtained by the Dumas method:

Weight of iodine taken . . . . . . 0.312 gram
Volume of air displaced . . . . . 50 cc.
Temperature of experiment . . . . . 227° C.
Barometric pressure . . . . 760 mm.

6. Calculate the molecular weight of a substance from the following data obtained by the Victor Meyer method:

Weight of substance taken . . . . . 0.184 gram
Volume of vapor obtained . . . . . 40 cc.
Temperature of experiment . . . . . 47° C.
Barometer reading . . . . 760 mm.

CHAPTER SEVENTEEN

FINDING THE MOLECULAR WEIGHTS OF NON–VOLATILE COMPOUNDS

WHEN a compound whose molecular weight is to be determined cannot be changed into a vapor, the preceding methods of finding its molecular weight cannot be used. Other methods based on certain characteristic behaviors of their solutions are employed.

I. ELEVATION OF THE BOILING POINT

A solid dissolved in a liquid changes the boiling point of that liquid. A definite mathematical relationship exists. The gram-molecular weight of cane sugar ($C_{12}H_{22}O_{11}$) — namely, ·342 grams — raises the boiling point of a liter of water from 100° C. to 100.52° C. The gram-molecular weight of phenol (94 grams) will produce exactly the same result. Different amounts of these substances, within certain limits, will produce a proportionate elevation of the boiling point, and the rise of the boiling point depends upon the number of particles of solute dissolved in the solution.

We can express this behavior mathematically, as follows:

$$Mol.\ Wt. = \frac{weight\ of\ solute\ in\ 1000\ g.\ of\ solvent}{elevation\ of\ B.P.\ as\ found}\,k \qquad (5)$$

For each solvent there is a **constant k** which represents the theoretical elevation produced by a gram-molecular weight of the solute dissolved in 1000 grams of solvent. The value of k for water is 0.52° C. For other solvents this value of k is different. This method is applicable to non-electrolytes of comparatively high boiling points.

MOLECULAR ELEVATION OF THE BOILING POINT

SOLVENT	CONSTANT k
Water	0.52° C.
Ethyl alcohol	1.15
Ether	2.11
Benzene	2.67
Chloroform	3.66

EXAMPLE. 36 grams of glucose when dissolved in a liter of water raised the boiling point 0.10° C. Determine the molecular weight of glucose.

From equation (5) we obtain, by substituting the values,

$$\text{Mol. Wt.} = 36 \times \frac{0.52}{0.10} = \frac{18.72}{0.1}$$

Mol. Wt. of glucose = 187.2

(The actual molecular weight of this compound is 180.)

Problems

7. 17.1 grams of sucrose raised the boiling point of 500 grams of water 0.052° C. What is the molecular weight of sucrose?

8. 60 grams of fructose when dissolved in a liter of water raised the boiling point of the water to 100.173° C. What is the molecular weight of this sugar?

9. 6.4 grams of naphthalene dissolved in 100 grams of benzene raised its boiling point 1.33° C. What is its molecular weight?

10. 15.2 grams of camphor raised the boiling point of ether, when dissolved in 100 grams of this solvent, 2.11° C. What is the molecular weight of camphor?

11. 78 grams of menthol, when dissolved in 1000 grams of ether, raised its boiling point 1.05° C. What is the molecular weight of menthol?

II. DEPRESSION OF THE FREEZING POINT

(RAOULT'S METHOD)

A solid dissolved in a liquid lowers the freezing point of the liquid. Here, again, a definite mathematical relationship exists. Each solvent has a constant of its own, representing the fictitious lowering of the freezing point caused by dissolving one gram-molecular weight of the substance in 1000 grams

of solvent. 342 grams of cane sugar and 94 grams of phenol each lower the freezing point of 1 liter of water from 0° C. to − 1.87° C. The lowering of the freezing point depends again on the number of particles dissolved in the solution. The mathematical formula for this behavior may be expressed as

$$Mol.\ Wt. = \frac{weight\ of\ solute\ in\ 1000\ g.\ of\ solvent}{lowering\ of\ F.\ P.\ as\ found}\ k \qquad (6)$$

MOLECULAR DEPRESSION OF THE FREEZING POINT

Solvent	Constant k
Water	1.87° C.
Formic acid	2.77
Acetic acid	3.90
Benzene	4.90
Phenol	7.40

EXAMPLE. 9.4 grams of phenol were dissolved in a liter of water whose freezing point was lowered 0.187° C. What is its molecular weight?

From equation (6) we obtain, by substituting the values,

$$Mol.\ Wt. = 9.4 \times \frac{1.87}{0.187} = \frac{17.58}{0.187}$$

Mol. Wt. of phenol = 94

Problems

12. 12.6 grams of dextrose dissolved in 100 grams of water lowered its freezing point to − 1.45° C. What is the molecular weight of dextrose?

13. 29.5 grams of acetamide when dissolved in a liter of water lowered its freezing point to − 0.93° C. What is its molecular weight?

14. 7.5 grams of tartaric acid dissolved in 100 grams of water lowered its freezing point 0.93° C. What is its molecular weight?

15. 0.164 gram of ethyl alcohol lowered the freezing point of 100 grams of benzene 0.175° C. What is the molecular weight of ethyl alcohol?

16. 12.8 grams of naphthalene dissolved in 100 grams of benzene lowered its freezing point 4.9° C. What is its molecular weight?

17. 42 grams of milk sugar lowered the freezing point of 1000 cc. of water 0.21° C. What is its molecular weight?

CHAPTER EIGHTEEN

FINDING THE ATOMIC WEIGHTS OF ELEMENTS EXISTING IN VOLATILE COMPOUNDS

IN finding the atomic weight of elements existing in volatile compounds, the simplest method to use is the following:

1. Select about six volatile compounds containing the element.
2. Determine their molecular weights from their vapor densities.
3. Analyze the compounds for their percentage composition.
4. Prepare a table as given below. Select a number of which all the weights of the element under investigation are multiples. This H.C.F. (highest common factor) is the atomic weight of the element.

DETERMINATION OF THE ATOMIC WEIGHT OF CHLORINE

COMPOUND	FORMULA	MOLECULAR WEIGHT	% CL	WEIGHT OF CHLORINE	H.C.F.
Hydrogen chloride	HCl	36.5	97.3	35.5	**35.5**
Phosphorus trichloride	PCl₃	137.0	77.7	106.4	or the
Bichloride of mercury	HgCl₂	270.0	26.3	70.9	*atomic*
Chlorine dioxide	ClO₂	67.0	53.0	35.5	*weight*
Phosgene	COCl₂	63.5	55.9	35.5	of
Chloroform	CHCl₃	119.5	89.1	106.5	*chlorine*

5. The larger the number of its volatile compounds analyzed, the surer can we be that the H.C.F. is the actual atomic weight, and not a multiple of the atomic weight.
6. If an element gives no volatile compounds, we can determine its atomic weight with the aid of Dulong and Petit's Law. The atomic weights found by the above method may be used in determining molecular weights of nonvolatile compounds.

EXAMPLE.   Determine the atomic weight of sulfur by the above method.

COMPOUND	FORMULA	MOLECULAR WEIGHT	% S	WEIGHT OF SULFUR	H.C.F.
Sulfur dioxide	SO_2	64	50.0	32	**32**, *or the*
Sulfur trioxide	SO_3	80	40.0	32	*atomic weight*
Sulfur chloride	$SOCl_2$	119	26.9	32	*of*
Hydrogen sulfide	H_2S	34	94.1	32	*sulfur*
Carbon bisulfide	CS_2	76	84.2	64	
Sulfuryl chloride	SO_2Cl_2	135	23.7	32	

Problems

18. Determine the atomic weight of carbon from the following of its volatile compounds: acetylene, C_2H_2; benzene, C_6H_6; formaldehyde, HCHO; ethyl alcohol, C_2H_5OH; methane CH_4; and acetic acid, CH_3COOH.
19. Determine the atomic weight of oxygen from at least five of its volatile compounds.
20. Determine the atomic weight of phosphorus from at least four of its volatile compounds.
21. Determine the atomic weight of hydrogen by the above method.

CHAPTER NINETEEN

FINDING THE ATOMIC WEIGHTS OF ELEMENTS WITH THE AID OF SPECIFIC HEATS

It is not possible to obtain, by the vapor-density method, the true atomic weights of those elements which cannot be vaporized. But by means of **Dulong and Petit's Law** (1818) the atomic weights of such elements can be calculated. It was found that the product of the atomic weight of a solid element and the specific heat of that element was approximately 6.4.

Specific heat × atomic weight = 6.4 (atomic heat)

The **specific heat** of a solid is the amount of heat necessary to raise the temperature of that substance 1° C. as compared with the amount of heat necessary to raise an equal weight of water 1° C.

Since specific heat is a physical constant which can be determined experimentally, the atomic weight of any solid element can be found by means of this specific heat. From the percentage composition of compounds containing the solid element under investigation, we can obtain a number which is either the true atomic weight of that element or a multiple of its atomic weight. With the aid of Dulong and Petit's Law we can by inspection decide which is the true atomic weight.

A. Example. 25 grams of tin are converted into stannic oxide, SnO_2. The stannic oxide is found to weigh 31.8 grams. The specific heat of tin is 0.055. Determine its atomic weight.

Since the SnO_2 weighed 31.8 grams and the tin originally weighed 25 grams, the difference of 6.8 grams must be the weight of the oyxgen which united with the tin. Hence

$$\begin{array}{cccc} 25 \text{ g.} & & 6.8 \text{ g.} & \\ \text{Sn} & + & O_2 & \longrightarrow \quad SnO_2 \\ x & & 32 & \end{array}$$
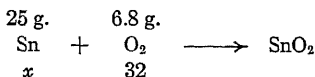
and x represents the atomic weight (also the Mol. Wt.) of tin.

Since $\dfrac{\text{Wt. of substance given}}{\text{Mol. Wt. of substance given}} = \dfrac{\text{Wt. of other substance}}{\text{Mol. Wt. of other substance}}$

Therefore $\dfrac{25}{x} = \dfrac{6.8}{32}$

and $x = \dfrac{25(32)}{6.8} = 118 =$ **apparent** atomic weight

118 may be a multiple of the real atomic weight, hence to check it, we determine the atomic weight by means of Dulong and Petit's Law.

Specific heat $\times$ atomic weight $= 6.4$

$$0.055(118) = 6.5 \text{ or approximately } 6.4$$

Therefore, 118 is the true atomic weight of tin.

Problems

22. Berzelius found that 4.2 grams of $MnCl_2$ yielded 9.57 grams AgCl. What is the atomic weight of silver if its specific heat is .055?

23. The same experimenter obtained 17.55 grams PbO from 16.3 grams of lead. The specific heat of lead is .030. What is its atomic weight?

24. A compound of hydrogen and sulfur has a molecular weight of 34. The percentage of sulfur is 94.11%. If the specific heat of sulfur is 0.163, what is its atomic weight?

25. Weatherill, in 1924, prepared and analyzed antimony trichloride and found that 2.75 grams $SbCl_3$ were equivalent to 3.9 grams of silver. The specific heat of antimony is 0.05. Determine the atomic weight of antimony. $(SbCl_3 \longrightarrow 3Ag)$

26. Honigschmid and Zintl prepared and analyzed the tetrabromide of hafnium discovered in 1923. They found that 1.92 grams of $HfBr_4$ were equivalent to 2.93 grams of AgBr. Determine the atomic weight of hafnium if its specific heat is .035. $(HfBr_4 \longrightarrow 4AgBr)$

27. According to Berzelius, 10 grams of platinum formed 24.74 grams of K_2PtCl_6. The specific heat of platinum is 0.03; what is its atomic weight?

28. 50 grams of lead were changed to 73.2 grams of lead sulfate. The specific heat of lead is 0.03; what is its atomic weight?

CHAPTER TWENTY

PROBLEMS BASED ON FARADAY'S LAWS

THE unit quantity of electricity, the **coulomb**, is that quantity of electricity which will deposit 1.118 milligrams of metallic silver from a silver salt solution. The electrochemical unit, the **Faraday**, is equal to 96,540 coulombs and corresponds to the electrical charge carried by one gram equivalent of an ion (1 gram H^+, 108 grams Ag^+, etc.). Univalent ions all carry the same quantity of electricity, while other ions carry amounts greater than this in proportion to their valencies.

The weights of the different substances which separate at each electrode throughout the circuit are proportional to the **equivalent weights** but independent of concentration, temperature, electrode surface, and voltage.

For example, 96,540 coulombs of electricity will liberate 1 gram of hydrogen, $\frac{16}{2}$ grams of oxygen, and $\frac{64}{2}$ grams of copper, and will decompose $\frac{98}{2}$ grams of sulfuric acid.

A. EXAMPLE. A certain current of electricity deposited 32 grams of copper. What weights of silver and of aluminum would this same current deposit?

Since equal quantities of electricity liberate chemically equivalent quantities of the ions, therefore,

$$\frac{\text{equivalent of copper}}{\text{weight of Cu deposited}} = \frac{\text{equivalent of silver}}{\text{weight of silver deposited}}$$

$$\text{or } \frac{\frac{64}{2}}{32} = \frac{\frac{108}{1}}{x}$$

$$x = 108 \text{ grams of silver}$$

Similarly,

$$\frac{\frac{64}{2}}{32} = \frac{\frac{27}{3}}{x}$$

$$x = 9 \text{ grams of aluminum}$$

B. EXAMPLE. A certain current liberated 5 grams of chlorine. What weight of calcium was deposited from the fused calcium chloride?

$$\frac{\text{equivalent of Cl}}{\text{grams of Cl liberated}} = \frac{\text{equivalent of calcium}}{\text{grams of calcium deposited}}$$

$$\frac{\frac{35.5}{1}}{5} = \frac{\frac{40}{2}}{x} \text{ (since Ca is divalent)}$$

$$35.5\, x = 100$$

$$x = 2.8 \text{ grams of Ca}$$

Problems

29. A current deposited 162 grams of silver. What weight of copper could this same current deposit?

30. 1 gram of potassium is deposited electrically. What weight of copper will the same current liberate from a copper sulfate solution?

31. A certain current liberated 50 grams of hydrogen in an hour. What weight of nickel would the same current deposit on spoons in a nickel sulfate bath?

32. Two electrolytic cells are arranged in series. One cell contains acidulated water and the other a solution of lead nitrate. When 35 cc. of hydrogen (standard conditions) have been liberated, what weight of lead nitrate has been decomposed?

33. What weights of copper can be replaced by (a) 50 grams of ferrous iron, (b) 65 grams of zinc, (c) 54 grams of aluminum, and (d) 12 grams of magnesium?

34. How many coulombs are carried by, and will deposit (a) 56 grams of silver, (b) 17.75 grams of chlorine, and (c) 100 grams of mercury (ic)?

CHAPTER TWENTY–ONE

SPECIFIC GRAVITY OF SOLUTIONS

THE **specific gravity** of a liquid is the number of times that liquid is as heavy as an equal volume of water. The specific gravity of a solution multiplied by its volume equals the weight of the solution, or,

$$\text{Sp. Gr.} \times \text{Vol. in cc.} = \text{Wt. in grams}$$

The specific gravity of a solution multiplied by its volume and again multiplied by the percentage of material in solution is equal to the weight of **solute** in the solution.

Thus 1 cc. H_2SO_4, of specific gravity 1.4 and containing 50 per cent H_2SO_4 by weight in solution, weighs **1.4 grams** and contains 1.4×0.50 or 0.70 gram of actual sulfuric acid dissolved in the water.

EXAMPLE. How many cubic centimeters of H_2SO_4 of Sp. Gr. 1.64, containing 72% sulfuric acid by weight, are required to react completely with 12 grams of magnesium?

This is a straight-weight problem.

$$
\begin{array}{ccc}
x \text{ grams} & 12 \text{ grams} & \\
H_2SO_4 & + \quad Mg & \longrightarrow MgSO_4 + H_2 \\
\dfrac{2 + 32 + 64}{98} & 24 &
\end{array}
$$
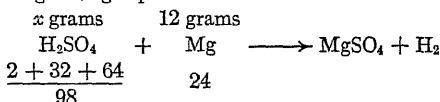
$$\frac{12}{24} = \frac{x}{98}, \qquad 2x = 98,$$

$$x = 49 \text{ grams of } 100\% \ H_2SO_4$$

Now since 1 cc. of the acid used contains 1.64×0.72 grams of pure H_2SO_4, we will require

$$\frac{49}{1.64(0.72)} \text{ or } 41.5 \text{ cc. of the above acid.}$$

Problems

35. What volume of HCl of Sp. Gr. 1.1, containing 20% HCl by weight, will be required to unite with 112 grams of iron to produce ferrous chloride?

36. Nitric acid of Sp. Gr. 1.37 contains 59.4% HNO_3 by weight. Calculate the number of cc. of this acid which will be needed to neutralize 180 grams of NaOH.

37. How many cubic centimeters of 30% HCl, Sp. Gr. 1.15, must be added to an ammonium hydroxide solution in order to form 10.7 grams of NH_4Cl?

38. How many cubic centimeters of 0.91% ammonia water, Sp. Gr. 0.996, are required to precipitate all the aluminum in 17.1 grams of $Al_2(SO_4)_3$?

39. How many cubic centimeters of 75% HNO_3, Sp. Gr. 1.44, will be required to dissolve completely 3.2 grams of pure copper?

40. Ammonium hydroxide of Sp. Gr. 0.898 contains 29% NH_3 by weight. What weight of ammonium sulfate will be formed by the neutralization of 500 cc. of sulfuric acid of Sp. Gr. 1.825 containing 91% H_2SO_4?

DILUTION OF SOLUTIONS TO A GIVEN DEGREE
OF SPECIFIC GRAVITY

When two mutually soluble substances are mixed, the resulting solution is not always equal to the sum of the original volumes. If we assume, however, that no change in volume takes place, the calculation is as follows:

If V is the volume of one solute of Sp. Gr. S, and V' is the volume of another solute of Sp. Gr. S', and if R is the volume of the resulting solution whose Sp. Gr. is S'', then,

$$VS + V'S' = RS''$$

But we are assuming that $V + V'$ is equal to R, therefore,

$$VS + V'S' = (V + V')S'' \quad . \quad . \quad . \quad . \quad (1)$$

A. EXAMPLE. Two lots of sulfuric acid, one of Sp. Gr. 1.72, and the other of Sp. Gr. 1.32, are available. What volumes of these acids must be mixed to make 500 cc. of H_2SO_4 of Sp. Gr. 1.6?

Let x = volume of H_2SO_4 of Sp. Gr. 1.72
Let y = volume of H_2SO_4 of Sp. Gr. 1.32

Since the sum of the weights must be equal, by substituting in equation (1) we obtain,

$$(1.72)x + (1.32)y = 1.6(500) = 800 \text{ grams} \quad . \quad . \quad . \quad . \quad (2)$$

We have assumed that no change in volume takes place, therefore

$$x + y = 500 \text{ cc.}$$

or

$$x = 500 - y$$

Substituting in (2) this value of x, we obtain,

$$(1.72)(500 - y) + (1.32)y = 800$$
$$860 - 1.72\,y + 1.32\,y = 800$$
$$- 0.4\,y = -60$$
$$y = 150 \text{ cc. of } H_2SO_4 \text{ (Sp. Gr. 1.32)}$$

and therefore

$$x = 350 \text{ cc. of } H_2SO_4 \text{ (Sp. Gr. 1.72)}$$

Problems

41. Two lots of hydrochloric acid are available. One lot has a specific gravity of 1.2 and the other of 1.05. What volumes of these acids must be mixed to make a liter of HCl of Sp. Gr. 1.16?

42. A manufacturer requires 100 liters of nitric acid of Sp. Gr. 1.45. He has on hand an acid of Sp. Gr. 1.5, and another of Sp. Gr. 1.31. What volumes of these acids must he mix?

43. A chemist requires 100 cc. of an ammonia solution of Sp. Gr. 0.89. He has in his laboratory some ammonia water of Sp. Gr. 0.882 and some other solution of Sp. Gr. 0.97. How much of each must he use to obtain the required ammonia water?

44. It is required to make 1500 cc. of sulfuric acid of Sp. Gr. 1.6. Two acids are available, one having a Sp. Gr. of 1.54 and another of Sp. Gr. 1.84. What volumes of these acids must be mixed?

45. 500 cc. of nitric acid of Sp. Gr. 1.19 must be prepared from two nitric acid solutions of Sp. Gr. 1.50 and 1.11. What volumes of the two acids must be used?

46. A chemist mixes a liter each of ammonia water of Sp. Gr. 0.99 and 0.91. What is the specific gravity of the resulting solution?

CHAPTER TWENTY–TWO

VOLUMETRIC ANALYSIS

VOLUMETRIC analysis involves the analysis of substances by means of solutions of which the chemical value is accurately known. Substances which can be obtained in a very pure condition, like Na_2CO_3, $AgNO_3$, $KMnO_4$, NaCl, and oxalic acid, can be accurately weighed and the desired volume of solution prepared. These solutions are called **standard solutions** and can be used to standardize other solutions whose strength cannot be so well adjusted. Thus we can determine the strength of hydrochloric acid by means of a standard sodium carbonate solution. The analytical operation is called a **titration**. The standard solution is placed in a graduated vessel, like a burette, and is then dropped into a solution of the substance to be estimated. By means of a suitable **indicator**, the completion of the chemical reaction taking place between the standard solution and the substance tested is shown by a change in color, formation of a precipitate, or some other visible sign. This point is called the **end-point**.

In determining the strength of a HCl solution the indicator used is methyl orange, which changes color when the reaction

$$Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + CO_2$$
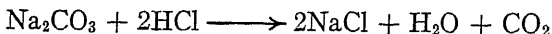
is completed.

Standard solutions are usually prepared as **normal** solutions or **molar** solutions.

A mole of a substance is its molecular weight in grams. For example, a mole of crystallized barium chloride ($BaCl_2 \cdot 2H_2O$) is 244.4 grams. A **molar solution** is one containing the gram-molecular weight of the solute dissolved in 1000 cc. of solution.

Problems

47. Find the weights of a mole of each of the following: hydrochloric acid, nitric acid, sulfuric acid, and acetic acid.
48. Calculate the weights of a mole of each of the following bases: sodium hydroxide, calcium hydroxide, ammonium hydroxide, and aluminum hydroxide.
49. Determine the molar weights of each of the following salts: sodium chloride, crystallized sodium carbonate, anhydrous copper sulfate, and sodium potassium tartrate.
50. What is the molar strength of a solution containing 87 grams of potassium sulfate in 250 cc. of water?

A **normal solution** is one containing one **equivalent** of the substance in 1000 cc. of the **solution** (not the solvent). In calculating the weights to be used in preparing normal solutions, therefore, the reaction in which the solution is to be used **must** be known.

By the equivalent of an **element** we mean that weight of the element which will replace or react with one gram of hydrogen. It corresponds to the atomic weight of the element divided by its valence. Thus the equivalents of chlorine, oxygen, and copper (cupric) are 35.5, 8, and 31.78, respectively.

The equivalent of an **acid** is that weight of the acid containing one gram of hydrogen. The equivalent of HCl is 36.5, the equivalent of H_2SO_4 is $\dfrac{98}{2}$, and of H_3PO_4 $\dfrac{98}{3}$.

The equivalent of a **base** is that weight of the base containing 17 grams of the hydroxyl (OH) group. The equivalent of NaOH is 40, and of $Fe(OH)_3$, $\dfrac{106.84}{3}$.

The equivalent of a **simple normal salt** is that weight of the salt which contains one equivalent of the metal or metallic radical. The equivalents of NaCl, $CuSO_4$, $AlCl_3$, and $Fe_2(SO_4)_3$ are 58.5, $\dfrac{159.6}{2}$, $\dfrac{133.5}{3}$, and $\dfrac{399.68}{6}$, respectively.

The equivalent of an **acid salt**, a **basic salt**, and a **complex salt** will depend upon the hydrogen, hydroxyl, metal, or radical with reference to which the equivalent is to be determined. Thus $\frac{232}{2}$, $\frac{232}{4}$, and $\frac{232}{6}$ are the equivalents of calcium, hydrogen, and the phosphate radical in $CaH_4(PO_4)_2$.

A. EXAMPLE. How would you prepare 15 cc. of a $\frac{N}{6}$ solution of potassium permanganate?

A normal solution of $KMnO_4$ contains one equivalent of $KMnO_4$ in 1000 cc. of the solution. One equivalent of $KMnO_4$ is equal to $39.1 + 54.9 + 64$, or 158 grams. 1000 cc. of a normal solution would contain 158 grams of $KMnO_4$. But we need a $\frac{N}{6}$ solution, therefore, 1000 cc. $\frac{N}{6}$ solution would contain $\frac{158}{6}$, or 26.33 grams. The problem calls for only 15 cc. Hence we should use $26.33 \times \frac{15}{1000}$, or 0.395 gram, to which enough water is added to make the final volume 15 cc.

B. EXAMPLE. What is the normality of a solution containing 35 mg. of silver (as $AgNO_3$) per cubic centimeter of solution?

A normal solution of $AgNO_3$ should contain the atomic weight of silver (a univalent element) expressed in grams per liter of solution. Therefore, it should contain only 107.88 grams of silver. Since it contains 50 grams per 1000 cc., its normality is

$$\frac{35}{107.88}, \text{ or } 0.324 \text{ N}$$

NOTE. If 10 grams of salt are dissolved in 90 grams of water, such a solution is called a **10% salt solution** and refers to the percentage of solute by weight in the solution. If 100 cc. of salt solution contains 10 grams of salt, we have a solution which may be described as containing 100 grams of salt per liter.

Problems

51. Calculate the amount of KNO_3 necessary to make 5 liters of $\frac{N}{5}$ solution of potassium nitrate.

52. How many grams of salt does half a liter of a 0.3 N sodium iodide solution contain?

53. How would you prepare 25 cc. of a tenth-normal solution of sodium carbonate?

54. What is the normality of a solution containing 75 mg. of copper, as $CuSO_4$, per cubic centimeter of solution?

55. How many grams of potassium permanganate must 695 cc. of $\frac{N}{5}$ solution contain?

56. What volume of $\frac{N}{5}$ sulfuric acid solution would be required to neutralize a solution of sodium carbonate containing 1 gram Na_2CO_3?

57. How much of a $\frac{N}{10}$ solution of hydrochloric acid will be needed to neutralize a limewater solution containing 0.02 gram of $Ca(OH)_2$ in solution?

58. What weight of silver nitrate will be required to make 10 liters of $\frac{N}{6}$ solution?

59. 1 cc. of a silver nitrate solution contains 0.0095 gram of silver. Calculate the normality of this solution.

60. How much pure potassium hydroxide must be dissolved in 1900 cc. of water to make a half-normal solution?

61. What weight of $Na_2CO_3 \cdot 10H_2O$ must be dissolved in 250 cc. of water to make a tenth-normal solution?

62. What weight of a 20% solution of NaOH will be required to neutralize 8 grams of a 50% solution of nitric acid?

63. How much of a 5% solution of hydrochloric acid will just neutralize 100 grams of a 50% solution of potassium hydroxide?

64. What is the normality of a solution of copper sulfate containing 0.016 gram of copper per cubic centimeter of solution?

I. STANDARD SOLUTIONS OF OXIDIZING AND REDUCING AGENTS

To prepare a standard solution of an oxidizing or reducing agent we must calculate what fractional part of the mole of the oxidizing or reducing agent contains one equivalent. This value will depend upon the reaction involved.

Some of the **common oxidizing agents**, and their reactions showing the number of atoms of oxygen acting as oxidizers, follow.

(1) **Chlorine**

$$Cl_2 + H_2O \longrightarrow 2HCl + O$$

(2) **Manganese dioxide**
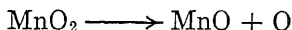
$$MnO_2 \longrightarrow MnO + O$$

(3) **Potassium nitrate**

$$2KNO_3 \longrightarrow K_2O + 2NO + 3O$$

(4) **Potassium permanganate**

$$2KMnO_4 \longrightarrow K_2O + 2MnO + 5O$$

(acid solution)

(5) **Hydrogen peroxide**

$$H_2O_2 \longrightarrow H_2O + O$$

(acid solution)

(6) **Potassium permanganate**

$$2KMnO_4 \longrightarrow K_2O + 2MnO_2 + 3O$$

(neutral and alkaline solution)
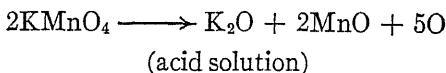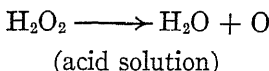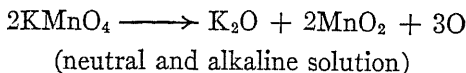
A. EXAMPLE. How much $KMnO_4$ must be weighed to make 100 cc. of $\frac{N}{5}$ solution of potassium permanganate to be used in an acid solution?

$KMnO_4$ in acid solution yields 5 atoms of oxygen.

Now since 5 oxygen atoms represent 10 equivalents, the quantity of $KMnO_4$ required to make a liter of normal solution will, according to definition, be equal to the weight of $2KMnO_4$ divided by 10, or, 31.6 grams. Hence to make 100 cc. of $\frac{N}{5}$ solution will require

$$\frac{31.6}{5} \times \frac{100}{1000} = 0.632 \text{ gram}$$

Problems

65. How many grams of potassium permanganate must 235 cc. of $\frac{N}{6}$ solution contain, for use as an oxidizing agent in the presence of sulfuric acid?

66. A liter of solution to be used in an oxidation reaction contains 50.5 grams of KNO_3. What is the normality of this solution?

67. What weight of $KMnO_4$ must 500 cc. of a $\frac{N}{2}$ solution contain, for use as an oxidizing agent in an alkaline solution?

68. Potassium bichromate is to be used as an oxidizing agent in an acid solution. How would you prepare 250 cc. of a $\frac{N}{5}$ solution of this reagent? $K_2Cr_2O_7 \longrightarrow Cr_2O_3 + K_2O + 3O$.

69. What weight of $K_4Fe(CN)_6 \cdot 3H_2O$ should a normal solution contain for use as a reducing agent? The equation for this reaction is
$$10K_4Fe(CN)_6 \cdot 3H_2O + 2KMnO_4 + 8H_2SO_4 \longrightarrow$$
$$10K_3Fe(CN)_6 + 6K_2SO_4 + 2MnSO_4 + 38H_2O$$

II. ADJUSTMENT OF THE STRENGTH OF SOLUTIONS

The normalities of two solutions vary inversely as the volumes they occupy. That is, $\frac{N}{N'} = \frac{V'}{V}$. Obviously, then, if N equals N', V must be equal to V', **or solutions of the same normality occupy equal volumes.**

This means that 1 cc. N HCl is equivalent to 1 cc. N NaOH, and 1 cc. N H_2SO_4 is equivalent to 1 cc. N $Ca(OH)_2$.

A. EXAMPLE. A solution of HNO_3 is of such strength that 1 cc. is equivalent to 0.045 gram of HNO_3. How much water must be added per liter to make the solution $\frac{N}{2}$?

1 cc. N HNO_3 contains 0.063 gram HNO_3 per liter, therefore the given solution is $\frac{45}{63}$ normal. But the required solution is to be $\frac{N}{2}$.

Since normalities vary inversely to volumes, therefore

$\frac{\frac{45}{63}N}{\frac{1}{2}N} = \frac{1+x}{1}$, where x = volume of H_2O to be added.

Solving for x, we obtain,
$$x = \frac{3}{7} \text{ liters or } 428.6 \text{ cc. } H_2O \text{ must be added.}$$

B. EXAMPLE. If you had on hand a $\frac{N}{5}$ silver nitrate solution, and wanted to make a solution containing 15 mg. of silver per cubic centimeter, to what extent would you have to dilute the original solution?

Let x = volume of water to be added to 1 cc. of the $\frac{N}{5}$ solution.

Then $x + 1$ = total number of cubic centimeters of final solution.
The weight of the silver does not change in the dilution, therefore,

$$15(x + 1) = \frac{N}{5} \text{ AgNO}_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Substituting for $\frac{N}{5}$ AgNO$_3$ the value $\frac{107.88 + 14 + 48}{5}$ or 34 mg. we obtain for equation (1)

$$15(x + 1) = 34$$
$$15\,x + 15 = 34$$
$$x = 1.267 \text{ cc. water}$$

Problems

70. 1 cc. of sulfuric acid is equivalent to 0.025 gram of sodium hydroxide. How much water must be added per liter to make it $\frac{N}{5}$?

71. How much water must be added to 1900 cc. of a sodium hydroxide solution, 1 cc. of which is equivalent to 0.045 gram of H$_2$SO$_4$, to make it half normal?

72. We have on hand 175 cc. of a solution of 0.35 normality. We wish to change this to a tenth-normal solution. How much water must we add?

73. We have on hand a normal solution of NaOH and some hydrochloric acid of unknown strength. 5 cc. of the NaOH solution required 7.5 cc. of the acid for neutralization. Determine the strength of the acid solution, and what volume of water would be required for dilution to make the solutions of equal normality?

74. 1 cc. of a solution of H$_2$SO$_4$ is equivalent to 0.03 gram of NaOH. How much water must be added per liter to make a half normal solution?

CHAPTER TWENTY–THREE

GRAVIMETRIC ANALYSIS

The term **gravimetric analysis** means essentially the weighing of a substance of known composition obtained from the material to be analyzed, and from this, calculating the amount of an element or radical present in the original material.

I. CALCULATIONS OF PERCENTAGE TO THE DRY BASIS

A. EXAMPLE. An ore contains 25% zinc and 8% water. What is the percentage of zinc, on the dry basis?

100 grams of zinc ore contain 25 grams Zn and 8 grams H_2O.
After all the water is removed, the ore weighs 92 grams, of which 25 grams are zinc. Therefore, the percentage of zinc on the dry basis is

$$\frac{25 \times 100}{92} = 27.17\%$$

B. EXAMPLE. A load of ore contains 30% copper, and, after exposure, 28% copper and 15% water. Find the percentage of water in the original load.

100 grams of the original sample contain 30 grams Cu and x grams H_2O
After exposure   28 grams Cu and 15 grams H_2O

The weight of Cu on the dry basis in the original sample was $\dfrac{30 \times 100}{100 - x}$.

The weight of Cu in the exposed load was $\dfrac{28 \times 100}{100 - 15}$.

But the actual weight of the copper has not changed, therefore,

$$\frac{30 \times 100}{100 - x} = \frac{28 \times 100}{100 - 15}$$
$$28(100 - x) = 30(100 - 15)$$
$$28\,x = 250$$
$$x = 8.93\% \text{ of water}$$

C. EXAMPLE. A sample of ore weighed 50 grams. When heated to 50° C. it lost 5% water. The partially dried sample was found to contain 3% water. Find the amount of water in the original sample of ore.

50 g. ore = 47.5 g. partially dried ore + 2.5 g. water.
47.5 g. partially dried ore = 47.5(0.97) g. dry ore + 47.5(0.03) g. H_2O.
Hence the total weight of the water = 2.5 g. + 47.5(0.03) g. = 3.925 g., which amounts to $\dfrac{3.925}{50} \times 100 = 7.85\%$ water.

Problems

75. An ore contains 8% moisture and 15% copper. What percentage of copper does the ore contain, on the dry basis?

76. What is the percentage of manganese in a dry ore which, before being heated, contained 12% moisture and 60% manganese?

77. An ore contained 15% lead and 10% zinc as well as 8% of moisture. What are the percentages of the two metals in the ore, on the dry basis?

78. An ore contained 12% water. When dried it contained 55.5% of metal. Find the percentage of metal in the dry ore.

79. An ore contained 1.23 grams of Fe_3O_4 and 0.105 gram of water. Calculate the percentage of magnetic oxide of iron present, on the dry basis.

80. The dry sample of an iron ore showed the presence of 65% iron. The natural ore contained 10% water. What was the percentage of iron in the natural ore?

81. A load of ore is found to contain 5.5% water. It is rained upon and found to contain 9.5% water, and to weigh 5000 lb. Find the weight of the original load of ore.

82. A sample of coal contained 8% of ash, on the dry basis. What is the percentage of ash in the natural coal containing 4% of moisture?

83. On analysis, an ore is found to consist of 47% of metal. When partially dried it is found to contain 7% water and 51% copper. Find the percentage of water in the original ore.

84. A sample of coal contained 1.2% sulfur and 2.4% water when partially dried. The original sample contained 1.1% sulfur. Find the percentage of water in the original sample of coal.

II. CALCULATIONS BASED ON THE USE OF FACTORS

A **chemical factor** is that number by which the weight of a compound must be multiplied to give the weight of the desired constituent. This corresponds to the percentage of the required substance in a given compound divided by 100. Thus the factor of NO_2 in KNO_3 is $\dfrac{NO_2}{KNO_3}$, or $\dfrac{14 + 32}{39 + 14 + 48}$, or 0.4554. (See Table of Factors on page 156.)

Factors are often used to simplify chemical calculations.

This is accomplished by weighing out a small multiple of the factor for analysis. Then if x grams of a substance taken for analysis gives P grams of precipitate, and if F represents the factor of that precipitate with respect to the substance analyzed,

$$\text{percentage of substance sought} = \frac{FP}{x} \times 100.$$

If a reaction takes place in more than one step, consider only the ratio between the actual weights involved.

EXAMPLE. How much of a sample of steel should an analyst take so that when all of the phosphorus in the steel is converted into $Mg_2P_2O_7$, this weight of $Mg_2P_2O_7$ in grams shall equal the percentage of phosphorus?

The factor for phosphorus in $Mg_2P_2O_7$ is equal to

$$\frac{2P}{Mg_2P_2O_7} = \frac{2(31)}{24.3 \times 2 + 31 \times 2 + 16 \times 7} = 0.278526$$

1 gram $Mg_2P_2O_7 \backsim 0.278526$ gram $P \backsim 1\%$ phosphorus
($\backsim$ stands for " is equivalent to ")
The weight of steel $\backsim 100\% \ P \backsim 27.8526$ grams steel.

Problems

85. How many grams of zinc ore must be taken for an analysis so that each milligram of $Zn_2P_2O_7$ shall be equivalent to 0.1 % zinc?

86. What weight in grams of bicarbonate of soda ($NaHCO_3$) must be taken in order that the weight of Na_2SO_4 in milligrams into which it is converted shall be equivalent to 100 % of bicarbonate?

87. How many grams of gold ore must be taken for an analysis so that each milligram of gold shall be equivalent to 1 troy ounce per ton? (A ton contains 29,166 troy ounces.)

CHAPTER TWENTY–FOUR

CHEMICAL PROBLEMS FROM COLLEGE ENTRANCE EXAMINATION BOARD PAPERS[1]

1916

88. Describe in detail how you should determine experimentally either (1) the hydrogen equivalent of some metal, or (2) the weight of a liter of some gas.

89. If the percentages of calcium in two samples of limestone are 40% and 80% respectively, what conclusion should you draw in regard to the specimens? State the law upon which your conclusion is based. (Atomic weights: Ca 40, O 16, C 12)

90. A body of air at constant pressure occupies a volume of 500 cc. at 20° C. At what temperature will its volume be 1000 cc.?

91. How many cc. of ammonia gas, NH_3, under standard conditions, can be obtained from 5 grams of ammonium phosphate, $(NH_4)_3PO_4$, by treating it with sodium hydroxide in excess? $(NH_4)_3PO_4 + 3NaOH = Na_3PO_4 + 3H_2O + 3NH_3$. (One liter of ammonia weighs 0.77 gram.)

92. Ten liters of a gas whose formula is C_2H_6O are completely burned in oxygen. How many liters of oxygen gas are required for its complete combustion? How many liters of carbon dioxide should result? All volumes are measured under the same conditions of temperature and pressure.

93. If the temperature of a gas enclosed at an initial pressure of one atmosphere is decreased from 37° C. to 27° C. without change in volume, what will be the final value of the pressure?

1917

94. Illustrate the law of multiple proportions by considering the composition by weight of two compounds containing the same elements.

[1] From *Examination Questions*, Fourth Series, 1916–1920. Copyright 1916, 1917, 1918, 1919, 1920, by the College Entrance Examination Board. Published by Ginn & Co., Boston and New York. Used by permission.

95. Excess of phosphorus is allowed to act on air at atmospheric pressure in a sealed flask. When the reaction is complete, (1) what is the pressure (approximately) in the flask, the temperature remaining the same? (2) How does the weight of the flask and its contents after the reaction compare with the weight before? State the law upon which the latter conclusion is based.

96. If 50 grams of calcium carbonate, $CaCO_3$, are added to 50 grams of hydrochloric acid, HCl, in water solution, which substance remains in excess?

97. What volume of nitric oxide, NO, measured under standard conditions, can be obtained by adding 10 grams of copper to excess of dilute nitric acid according to the equation:

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 4H_2O + 2NO?$$
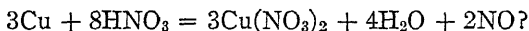
(One liter of nitric oxide at 0° C. and 760 mm. weighs 1.34 grams.)

98. State Gay-Lussac's Law of Combining Volumes. What volume of oxygen is required for the complete combustion of five liters of acetylene, C_2H_2? All measurements are to be made under the same conditions of temperature and pressure.

99. One liter of gas A weighs 1.98 grams. One liter of gas B weighs 0.77 gram, under the same conditions. The molecular weight of A is 44. What is the molecular weight of B?

1918

100. What is the percentage of ammonia in cuprammonium sulfate, $CuSO_4 \cdot 4NH_3 \cdot H_2O$? (One liter of carbon dioxide at 0° C. and 760 mm. weighs 1.98 grams.)

101. What weight of pure sodium bicarbonate, $NaHCO_3$, must be treated with excess of acid to produce 250 liters of carbon dioxide measured at 0° C. and 1520 mm. pressure? (One liter of carbon dioxide at 0° C. and 760 mm. weighs 1.98 grams.)

102. What weight of sulfur dioxide will occupy a volume equal to that of 42 grams of nitrogen at the same temperature and pressure?

103. What volume of a solution of hydrochloric acid containing 73 grams per liter would suffice for the exact neutralization of the sodium hydroxide obtained by allowing 0.46 gram of metallic sodium to act on water?

1919

104. How many grams of sodium hydroxide will be required to neutralize 9.8 grams of sulfuric acid? Name the products formed and determine the weight of each product.

105. What volume will one liter of gas at 136.5° absolute have at 136.5° C., pressure remaining the same?

106. Apply Avogadro's Law in finding the volume of carbon dioxide formed from the burning of 4 liters of carbon monoxide in oxygen, provided all of the gases are measured at the same temperature and pressure.

1920

107. Describe an experiment illustrating the quantitative character of chemical action, including apparatus, method, and precautions. Show how the data found in the experiment warrant the conclusion reached. The data may be represented by letters.

108. If 540 grams of silver react with an excess of concentrated sulfuric acid according to the equation

$$2Ag + 2H_2SO_4 \longrightarrow Ag_2SO_4 + 2H_2O + SO_2,$$
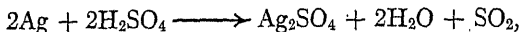
what weight of silver sulfate, and what volume of sulfur dioxide measured under standard conditions of temperature and pressure, will be formed?

109. A dirigible balloon at sea level contains 400,000 cubic feet of gas measured at a pressure of 774 mm. of mercury and at a temperature of 27° C. It rises to an elevation at which the pressure is reduced to 430 mm. and the temperature to − 23° C. What is the volume of the gas under the latter conditions, assuming that none is allowed to escape from the containers?

CHEMICAL PROBLEMS FROM COLLEGE ENTRANCE EXAMINATION BOARD PAPERS

(*Comprehensive Examinations*)

1916

110. A certain quantity of magnesium dissolved in acid gave exactly 100 cc. of dry hydrogen at a temperature of 22° C. and a pressure of 780 mm. How many grams of metal were used? Compute the result to three significant figures. (A liter of hydrogen at 0° C. and 760 mm. weighs 0.09 gram.)

111. At standard temperature and pressure, one liter of gaseous element A unites with three liters of the gaseous element B, to make two liters of the gas C. If each molecule of C contains one atom of A, what is the simplest formula for a molecule of the element A? Show clearly how you arrive at your conclusion.

112. One gram of pure iron forms 1.43 grams of an oxide. Find (*a*) the percentage composition of this oxide of iron, (*b*) its simplest formula, and (*c*) the equivalent weight of iron in the compound.

113. Calculate the percentage of oxygen in crystallized copper nitrate, $Cu(NO_3)_2 \cdot 6H_2O$.

114. What weight, and volume at 0° C. and 760 mm., of carbon dioxide can be obtained by treating an excess of sodium acid carbonate with 490 grams of sulfuric acid containing 20% H_2SO_4?

115. A compound has the following composition: carbon 54.67%, hydrogen 9.11%, oxygen 36.22%. Find the simplest formula for this substance.

116. A body of air at constant pressure occupies a volume of 500 cc. at 20° C. At what temperature will its volume become 1000 cc.?

117. How many liters of ammonia gas, measured under standard conditions, can be obtained when 20 grams of sodium hydroxide react with an excess of ammonium sulfate?

1917

118. State the Law of Multiple Proportions and illustrate it by the consideration of two compounds of carbon and hydrogen containing respectively 75% and 92.3% of carbon.

119. How many grams of hydrochloric acid can be obtained by heating 10 grams of crystallized ferric chloride, $FeCl_3 \cdot 6H_2O$, with concentrated sulfuric acid?

120. What is the percentage of iron in iron alum, $K_2SO_4 \cdot Fe_2(SO_4)_3 \cdot 24H_2O$?

121. What volume would be occupied by 14 grams of CO under standard conditions?

122. If 10 liters of CO under standard conditions are heated to 27.3° C. without change in pressure, what volume will the gas occupy?

123. What volume of oxygen is necessary to combine with 5 liters of CO under the same conditions of temperature and pressure?

124. A certain chemical compound is found by analysis to contain 92.3% of carbon and 7.7% of hydrogen. What is the simplest formula which can express its composition? If the molecular weight is 78, what is the formula?

125. Define the term "molecular weight" and give one method for determining a molecular weight.

126. State Gay-Lussac's Law of Combining Gas Volumes, and illustrate with an example. State the hypothesis which serves to explain the facts generalized by this law.

127. 30 grams of chlorine are to be united with hydrogen. What volume of hydrogen is required at 0° C. and 760 mm., and what volume of HCl results under the same conditions?

128. A balloon requires for adequate inflation 5000 gram-molecular volumes (or an equal number of gram molecules) of hydrogen measured at normal temperature and pressure. What is the cost of inflating such a balloon if scrap iron at 1¢ per kg. and H_2SO_4 containing 20% acid at 4¢ per kg., are used for generating the hydrogen?

129. 1.0085 grams of pure tin foil were oxidized with nitric acid, and the final weight of the highly ignited oxide was

1.2790 grams. From the data submitted, find the percentage composition and the simplest formula of this oxide of tin.

1918

130. Calculate the weight of MnO_2 required to produce chlorine enough to fill a flask of 4 liters capacity when the barometer stands at 760 mm. and the temperature is 0° C.

131. What weight of manganese dioxide would be required if the flask were filled at 760 mm. and 273° C.?

132. What is a normal solution of an acid and of an alkali?

133. 10 cc. of ordinary household ammonia are neutralized by the addition of 40 cc. of a normal solution of HCl. What weight of ammonia gas, NH_3, is contained in each cubic centimeter of the original solution?

134. 1.8 grams of magnesium displace from acid 1820 cc. of hydrogen, measured dry at 740 mm. and 20° C. Find the volume of this gas under standard conditions and determine the valence of magnesium.

135. 10 grams of crystallized ammonium carbonate, $(NH_4)_2CO_3 \cdot H_2O$, are heated until completely decomposed into ammonia, carbon dioxide, and steam. What will be the total volume of these products at 273° C. and 760 mm. pressure?

136. State Avogadro's Law and show in detail how this law guides the chemist in determining the molecular weights of gases and vapors.

137. 2 grams of finely divided nickel are heated with a quantity of sulfur slightly in excess of that needed for complete combination until the chemical action is completed and the excess of sulfur is vaporized. The weight of the product formed is 3.09 grams. Find the percentage composition and simplest formula of this compound.

1919

138. How many cc. of oxygen, measured at 0° C. and 760 mm., can be obtained by the complete decomposition of 1 kg. of 3% solution of H_2O_2, into water and oxygen?

139. What is the percentage of silica, SiO_2, in the mineral analcite, $Na_2SiO_3 \cdot Al_2(SiO_3)_3 \cdot 2H_2O$?

140. State the Law of Multiple Proportions and give two substances to illustrate this law, with the percentage composition in each case.

141. 100 liters of dry air at 20° C. and 760 mm. contain 0.078 gram of carbon dioxide. What is the proportion by volume of CO_2 present in the air?

142. How many cc. of carbon dioxide measured at 0° C. and 760 mm. will be absorbed by a solution containing 2 grams of sodium hydroxide, to form sodium carbonate and water?

143. The formula of a gaseous compound is C_2H_2. Calculate its percentage composition and its vapor density.

144. Give directions for making a normal solution of sulfuric acid and one of sodium hydroxide.

145. 10 cc. of a normal solution of sulfuric acid require 2.5 cc. of a solution of NaOH for complete neutralization. Find the concentration of the solution of NaOH in grams per liter.

146. Calculate the molecular weight of carbon dioxide gas from the following data, showing every step in the calculation:

Weight of flask filled with CO_2, dry . 102.38 grams
Weight of flask filled with air, dry . 101.56 grams
Temperature of measured gases . . 0° C.
Pressure of measured gases . . . . 770 mm.
Volume of flask . . . . 1200 cc.

One liter of air weighs 1.29 grams at 0° C. and 760 mm.

147. 5 liters of CO are mixed with just enough oxygen for complete combustion and the mixture is ignited. If the original gases are measured at 20° C., at what temperature will the product occupy the same volume, the pressure remaining the same?

1920

148. How much cream of tartar ($HKC_4H_4O_6$) should be mixed with 1 kg. of baking soda ($NaHCO_3$) so that neither ingredient will be in excess?

149. What volume of carbon dioxide at 0° C. and 760 mm. may be obtained from the baking powder thus made?

150. What is the relation between volume and pressure of a gas when the temperature is constant? between volume and temperature when the pressure is constant? between temperature and pressure when volume is constant?

151. From the standpoint of the molecular hypothesis, explain the fact that (1) 40 gallons of oxygen may be forced into a small steel cylinder, (2) gas escapes from a glass of soda water, (3) chlorine gas, although heavier than air, escapes from an upright vessel.

152. Tell how you would determine experimentally the equivalent of some element or the molecular weight of some gas.

153. A portable gas stove used in heating a room burns natural gas (assumed to be pure methane, CH_4) and consumes in one hour 10 cubic feet of gas measured at a pressure of 30 inches of mercury and a temperature of 60° F. What volume of oxygen is consumed and what space is occupied by the carbon dioxide which is produced, when measured under conditions of temperature and pressure previously specified?

154. 2 gram molecules of the oxide RO combine with 44.8 liters of oxygen at 0° C. and 380 mm. The volume of the product under the same conditions is nearly equal to that of the oxygen taken. Calculate the formula of the product.

155. 50 cc. of a solution containing 40 grams of NaOH per liter neutralize 40 cc. of a solution of HCl. What is the concentration of the acid solution in grams per liter?

156. How many grams of potash alum, $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$, can be made from 69 grams of bauxite $(Al_2O_3 \cdot 2H_2O)$?

157. A liter of a certain elementary gas weighs 7.5 grams, while a liter of hydrogen gas under the same conditions weighs 0.09 gram. The atomic weight of the element composing the gas is 75. How many atoms are there in a molecule of the gas?

158. A certain weight of potassium carbonate, heated with 10 grams of sand, gives 25.6 grams of potassium silicate according to the equation $K_2CO_3 + SiO_2 \longrightarrow K_2SiO_3 + CO_2$. Calculate the weight of the potassium carbonate.

159. What is the percentage of sulfur trioxide in white vitriol $(ZnSO_4 \cdot 7H_2O)$?

160. Assume x to be a gaseous element having a valence of 3 and containing 2 atoms per molecule. To make 2 volumes of its gaseous compound with hydrogen, how many volumes of each constituent are required? State the law upon which your conclusion is based.

PART THREE

1. OXYGEN AND OZONE

Lab. Prep. $\begin{cases} 2HgO \longrightarrow 2Hg + \uparrow O_2 \text{ (Decomposition of mercuric oxide)} \\ 2KClO_3 \longrightarrow 2KCl + \uparrow 3O_2 \text{ (Decomposition of } KClO_3) \end{cases}$

Com. Prep. $\begin{cases} 2H_2O \longrightarrow 2H_2 + O_2 \text{ (Electrolysis of water)} \\ 3O_2 \longrightarrow 2O_3 \text{ (Passage of a silent electric discharge through} \\ \quad \text{air)} \end{cases}$

Chem. Prop. $\begin{cases} 4P + 5O_2 \longrightarrow 2P_2O_5 \text{ (Unites with non-metals to form} \\ \quad \text{oxides)} \\ 2Cu + O_2 \longrightarrow 2CuO \text{ (Unites with metals to form oxides)} \\ 2Ag + 2O_3 \longrightarrow Ag_2O_2 + 2O_2 \text{ (Very strong oxidizing agent)} \end{cases}$

1. Calculate the percentage composition of $Ca(ClO_3)_2$.

2. How much mercury and oxygen can be obtained from 108 grams of mercuric oxide?

3. What weight of oxygen can be obtained from 245 lb. of potassium chlorate?

4. How many grams of cupric oxide (CuO) could be obtained by heating 1 gram of copper in the air?

5. What weight of carbon dioxide is formed by burning 240 lb. of coal containing 11% impurities?

6. A certain weight of potassium chlorate was heated. The KCl formed weighed 149 grams. What weight of $KClO_3$ was used?

7. How much mercury will remain after obtaining 160 grams of oxygen from mercuric oxide?

8. What is the vapor density of ozone if 325 cc. weigh 0.702 gram?

9. 1000 liters of pure oxygen are required. What weight of water would have to be decomposed?

10. How many liters of oxygen would be required to burn 6.2 grams of phosphorus completely?

11. What volume of ozone can be obtained from 32 grams of oxygen?

12. 112 grams of iron gave 160 grams of Fe_2O_3. What is the atomic weight of oxygen?

2. HYDROGEN

Lab. Prep.
$\begin{cases} Zn + H_2SO_4 \longrightarrow \uparrow H_2 + ZnSO_4 \text{ (Action of a metal on} \\ \text{an acid)} \\ 2Na + 2H_2O \longrightarrow 2NaOH + \uparrow H_2 \text{ (Action of sodium on} \\ \text{water)} \end{cases}$

Com. Prep.
$\begin{cases} 2H_2O \longrightarrow 2H_2 + O_2 \text{ (Electrolysis of water)} \\ 3Fe + 4H_2O \longrightarrow Fe_3O_4 + \uparrow 4H_2 \text{ (Action of steam on hot} \\ \text{iron)} \end{cases}$

Chem. Prop.
$\begin{cases} H_2 + Cl_2 \longrightarrow 2HCl \text{ (Strong affinity for chlorine)} \\ CuO + H_2 \longrightarrow Cu + H_2O \text{ (Reducing agent)} \end{cases}$

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13. Calculate the percentage of hydrogen present in microcosmic salt, $HNaNH_4PO_4 \cdot 4H_2O$.

14. How many liters of steam result from the burning of 1500 cc. of hydrogen?

15. How many grams of zinc would be required to replace all the hydrogen from 49 grams of sulfuric acid? What weight of $ZnSO_4$ would be formed?

16. 6.5 grams of zinc react with an excess of dilute hydrochloric acid. What weights of the products will be formed?

17. A balloon holds 200 kg. of hydrogen when filled. What weights of zinc and sulfuric acid are necessary to furnish sufficient gas to fill this balloon?

18. Calculate the weight of steam that could be reduced by a ton of red-hot coke containing 95% pure carbon.

19. What weight of hydrogen must unite with 500 cc. of oxygen and leave no oxygen free?

20. By the action of 69 grams of sodium on water, how many liters of gas will be formed when measured over water at 20° C. and 765 mm., the height of the water outside the tube being 13 cm. above the height of the water inside the measuring tube?

21. Which will produce more hydrogen, — the action on water of 46 grams of sodium or 78 grams of potassium?

22. Calculate the hydrogen equivalent of cadmium, if 0.112 gram of cadmium released 24.4 cc. of hydrogen at 20° C. and 740 mm.

23. A certain weight of copper oxide when heated in a current of hydrogen lost 60 grams of oxygen and formed 67.5 grams of water. What is the atomic weight of hydrogen?

24. 500 cc. of a gas weigh 0.38 gram. It is composed of hydrogen and nitrogen, the hydrogen weighing $\frac{3}{17}$ of the whole. What is the true formula of this gas?

3. WATER AND HYDROGEN PEROXIDE

Lab. Prep. $\begin{cases} 2H_2 + O_2 \longrightarrow 2H_2O \text{ (Passage of electric spark through} \\ \quad \text{mixture of } O_2 \text{ and } H_2) \\ BaO_2 + H_2SO_4 \longrightarrow \downarrow BaSO_4 + H_2O_2 \text{ (Action of barium} \\ \quad \text{peroxide and sulfuric acid)} \end{cases}$

Chem. Prop. $\begin{cases} CuSO_4 + 5H_2O \longrightarrow CuSO_4 \cdot 5H_2O \text{ (Water of crystalliza-} \\ \quad \text{tion)} \\ CaO + H_2O \longrightarrow Ca(OH)_2 \\ C_{12}H_{22}O_{11} \longrightarrow 12C + 11H_2O \\ H_2O_2 \longrightarrow H_2O + \uparrow O \text{ (Instability of } H_2O_2) \end{cases}$
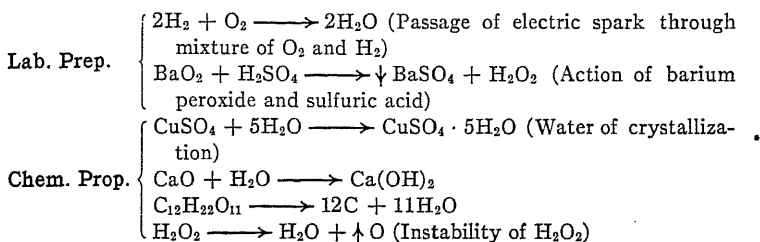
25. Calculate the percentage composition of copperas, $FeSO_4 \cdot 7H_2O$.

26. What per cent of water does alum, $KAl(SO_4)_2 \cdot 12H_2O$, contain?

27. The weight of 1 liter of water vapor was found to be equal to 0.81 gram. Calculate its specific gravity, and molecular weight.

28. Calculate the weight of 70% sulfuric acid necessary to react with 16.9 grams of barium peroxide to produce pure hydrogen peroxide.

29. How many cubic centimeters of free oxygen are liberated when 84.5 grams of pure hydrogen peroxide decompose?

30. The following results were obtained in the gravimetric determination of water: Loss of weight of CuO 10.83 grams, weight of water formed 12.2 grams. Calculate the ratio in which hydrogen and oxygen combined.

31. How many liters of steam result by burning 5 liters of hydrogen?

32. 15 cc. of oxygen collected in a eudiometer measured over mercury, were mixed with hydrogen gas until the mixture measured 22.4 cc. The gases were then exploded by means of an electric spark. What gas was left, and what was the volume of the resulting gas?

33. How many grams of $Sr(NO_3)_2 \cdot 5H_2O$ may be obtained from 100 grams of a mineral containing only 55% of $SrCO_3$?

34. Find the formula of crystallized copper sulfate, 7.84 grams of which lost 2.79 grams of water after being heated.

35. 70 grams of a solution of hydrogen peroxide on decomposing gave 2.6 liters of oxygen. What was the percentage of H_2O_2 in the solution?

36. In one of Dumas' experiments on the composition of water, the following data were obtained:
    Weight of CuO + tube before experiment . . 334.596 g.
    Weight of CuO + tube after experiment . . 314.236 g.
    Weight of drying tube before experiment . . 426.358 g.
    Weight of drying tube after experiment . . . 449.268 g.
    Determine the composition of water by weight.

4. CHLORINE

Lab. Prep. $\begin{cases} 4HCl + MnO_2 \longrightarrow MnCl_2 + 2H_2O + \uparrow Cl_2 \text{ (Oxidation} \\ \text{of HCl)} \\ 2KCl + MnO_2 + 2H_2SO_4 \longrightarrow K_2SO_4 + MnSO_4 + 2H_2O \\ + \uparrow Cl_2 \end{cases}$

Com. Prep. $\begin{cases} 2NaCl + 2H_2O \longrightarrow 2NaOH + \uparrow H_2 + \uparrow Cl_2 \quad \text{(Elec-} \\ \text{trolysis of brine)} \end{cases}$

Chem. Prop. $\begin{cases} Cu + Cl_2 \longrightarrow CuCl_2 \text{ (Unites with metals to form chlo-} \\ \text{rides)} \\ 2FeCl_2 + Cl_2 \longrightarrow 2FeCl_3 \text{ (Oxidizing agent)} \\ H_2O + Cl_2 \longrightarrow 2HCl + \uparrow O \text{ (Liberates nascent O from} \\ \text{water)} \end{cases}$

37. Find the percentage of chlorine present in bleaching powder containing 90% of $CaOCl_2$.

38. How many grams of chlorine can be made by the use of 174 grams of manganese dioxide?

39. How many grams of manganese chloride are formed in the above reaction?

40. A load of tin cans was treated with chlorine and 26.1 lb. of stannic chloride, $SnCl_4$, were obtained. How much tin was present in the tin cans?

41. The vapor density of chlorine was found to be 35.5. Determine its specific gravity, weight of a liter, and molecular weight.

42. What weight of sodium chloride must be decomposed to liberate 100 liters of chlorine gas?

43. How many cubic centimeters of oxygen will be liberated when a volume of chlorine water, containing 1 gram of chlorine in solution, is completely decomposed?

44. What volume of chlorine can be obtained by the electrolysis of a brine solution containing 5 kilograms of sodium chloride?

45. If 261 grams of pyrolusite (91% pure MnO_2) are treated with an excess of hydrochloric acid, what is the volume of the gas liberated?

46. 5 liters of chlorine are burned in a sufficient volume of hydrogen gas. What volume of hydrogen chloride gas is produced?

47. 91 grams of silver when heated in chlorine yield 121 grams of silver chloride. What is the atomic weight of chlorine?

48. A chemist determined the atomic weight of chlorine found in NH_4Cl contained in some mine water by finding the ratio of Ag to AgCl. The following figures were obtained: 0.8 gram of silver gave 1.06 grams of AgCl. What was the atomic weight of the chlorine found?

5. HYDROGEN CHLORIDE AND HYDROCHLORIC ACID

Lab. Prep. $\begin{cases} NaCl + H_2SO_4 \longrightarrow NaHSO_4 + \uparrow HCl \text{ (Action of } H_2SO_4 \\ \quad \text{on a chloride)} \\ H_2 + Cl_2 \longrightarrow 2HCl \text{ (Direct union of the elements)} \end{cases}$

Com. Prep. $2NaCl + H_2SO_4 \longrightarrow Na_2SO_4 + \uparrow 2HCl$

Chem. Prop. $\begin{cases} Zn + 2HCl \longrightarrow \uparrow H_2 + ZnCl_2 \text{ (Reacts with some metals} \\ \quad \text{liberating } H_2) \\ ZnO + 2HCl \longrightarrow ZnCl_2 + H_2O \text{ (Forms water with} \\ \quad \text{metallic oxides)} \\ NaCl + AgNO_3 \longrightarrow NaNO_3 + \downarrow AgCl \text{ (Test for a} \\ \quad \text{chloride)} \end{cases}$

49. The vapor density of hydrogen chloride gas was found to be 18.24. Determine the weight of a liter of this compound as well as its specific gravity (air standard).

50. 164 cc. of hydrogen chloride gas under standard conditions weighed 0.269 gram. Find (a) its vapor density, and (b) the weight of 5 liters of this gas.

51. Find the number of grams of hydrogen chloride set free by the complete reaction between 32 grams of sulfuric acid and sufficient sodium chloride.

52. How many grams of potassium chloride and sulfuric acid (65% by weight) are necessary to produce 2.8 grams of hydrogen chloride?

53. 28.4 grams of sodium sulfate are found after sulfuric acid reacts with sodium chloride. How much of the latter was used?

54. A 25% hydrochloric acid solution has a specific gravity of 1.125. Determine the weight of such an acid necessary to dissolve completely 56 grams of iron to form ferrous chloride, $FeCl_2$.

55. 50 cc. of hydrogen are liberated when hydrochloric acid reacts with a metal. What weight of acid was decomposed?

56. 143.5 grams of silver chloride are precipitated out of a potassium chloride solution by means of silver nitrate. How much KCl reacted with the silver nitrate?

57. What volumes of hydrogen and chlorine will be necessary to prepare 5.5 liters of hydrogen chloride gas by direct union of the elements?

58. 20 cc. of chlorine gas and 25 cc. of hydrogen gas are placed in a measuring tube and electric sparks passed through the mixture. What volume of hydrogen chloride can be theoretically obtained? What volume of any other gas will be found in the tube?

59. Calculate the volume of hydrochloric acid, containing 20% HCl by weight (Sp. Gr., 1.1), necessary to neutralize 37.37 grams of calcium hydroxide.

6. ALKALI METALS, BASES, AND NEUTRALIZATION

Com. Prep. $2NaOH \longrightarrow 2Na + \uparrow H_2 + \uparrow O_2$ (Electrolysis of fused NaOH)

Chem. Prop. $\begin{cases} 2K + 2H_2O \longrightarrow 2KOH + \uparrow H_2 \text{ (Liberates hydrogen from water)} \\ 2Na + O_2 \longrightarrow Na_2O_2 \text{ (Unites with oxygen readily)} \\ 2Li + Cl_2 \longrightarrow 2LiCl \text{ (Reacts with chlorine vigorously)} \\ NaOH + HCl \longrightarrow NaCl + H_2O \text{ (Neutralized by acids)} \end{cases}$
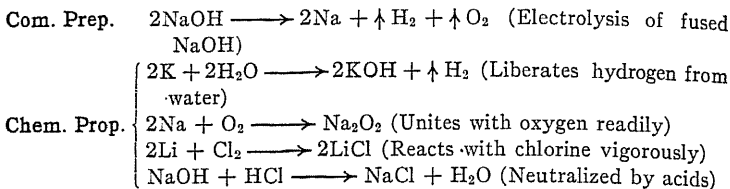
60. What percentage of sodium and nitrogen does sodium cyanide (NaCN) contain?

61. What weight of metallic sodium can be obtained by the electrolysis of 80 lb. of fused sodium hydroxide containing 2% impurities?

62. A gram of rock gave on analysis 0.113 gram of K_2PtCl_6. Find the percentage of potassium available in this ore.

63. Which will require more water to dissolve completely: 45 grams of sodium or 79 grams of potassium?

64. What weight of potassium chloride can be obtained by reacting 500 cc. of chlorine with sufficient potassium? How much potassium will be required?

65. 10 grams of a mixture of NaCl and KCl yielded 20.5 grams of AgCl. Determine the percentage of each salt in the mixture.

66. A piece of sodium is thrown on water. The sodium hydroxide formed just neutralized 98 grams of sulfuric acid. What weight of sodium was used?

67. A certain weight of sodium hydroxide was neutralized with sulfuric acid. The solution on evaporation yielded 15.5 grams of sodium sulfate. What weight of caustic soda was neutralized?

68. Calculate the volumes of hydrogen and oxygen produced during the electrolysis of 112 grams of fused potassium hydroxide. What weight of potassium would be formed at the same time?

69. Calculate the formula of a compound having the following composition: potassium, 16%; platinum, 40.4%; and chlorine, 43.6%.

70. What volume of chlorine will be required to change completely 70 grams of lithium to its chloride? What weight of lithium chloride will be formed?

71. Caustic potash costs $7\frac{1}{5}$¢ per pound and contains 10% of water. Caustic soda sells at $3.25 per 100 lb. and contains 24% of water. Which would be cheaper to use in neutralizing a given weight of sulfuric acid?

7. SODIUM SALTS

Com. Prep. $\begin{cases} NaCl + NH_4OH + CO_2 \longrightarrow NaHCO_3 + NH_4Cl \text{ (Solvay} \\ \text{process for the manufacture of } Na_2CO_3) \\ 2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + \uparrow CO_2 \end{cases}$

Lab. Prep. $\quad 2NaOH + H_2O + CO_2 \longrightarrow Na_2CO_3 + 2H_2O$

Chem. Prop. $\begin{cases} Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + \uparrow CO_2 \quad \text{(Decom-} \\ \text{posed by acids liberating carbon dioxide)} \\ Na_2CO_3 \cdot 10H_2O + CO_2 \longrightarrow 2NaHCO_3 + 9H_2O \\ NaHCO_3 + KHC_4H_4O_6 \longrightarrow KNaC_4H_4O_6 + H_2O + \uparrow CO_2 \\ \text{(Action of baking powder)} \end{cases}$

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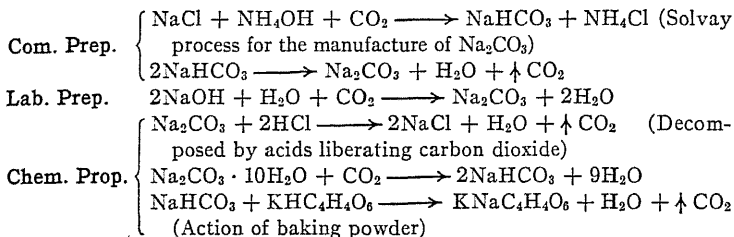
72. How much sodium carbonate can be obtained from a ton of sodium bicarbonate?

73. Sodium bicarbonate sells at \$2 per 100 lb., and sodium carbonate at \$1.30 per 100 lb. Which would be cheaper to use in the preparation of 5 cu. ft. of carbon dioxide?

74. How many grams of sulfuric acid will be needed to liberate all the carbon dioxide from 22 grams of washing soda?

75. A fire extinguisher holds 2.5 lb. of sodium bicarbonate in solution. What weight of sulfuric acid will be required to liberate all of its carbon dioxide?

76. 2000 lb. of sodium bicarbonate are available. What weight of potassium acid tartrate must be used to make enough baking powder to use all of this available bicarbonate?

77. What volume of carbon dioxide will be liberated when hydrochloric acid reacts with 42 grams of sodium bicarbonate?

78. 256 grams of sodium bicarbonate are heated. What weight of sodium carbonate and what volume of carbon dioxide are formed?

79. 4.3 grams of Rochelle salts ($KNaC_4H_4O_6$) were found present in a cake after baking. What weight of baking powder was used in the recipe?

80. Equal weights being taken, which will neutralize a greater amount of acid, sodium carbonate or sodium bicarbonate?

81. Hydrochloric acid completely neutralized potassium acid carbonate ($KHCO_3$), and 50 cc. of carbon dioxide were liberated. What weight of the bicarbonate was neutralized?

82. 8 grams of crystallized sodium sulfate lost 4.4 grams of water upon being heated. Derive the formula of the crystalline salt.

83. What weight of baking powder can be made from 168 lb. of sodium bicarbonate and 282 lb. of cream of tartar?

8. SULFUR AND SULFIDES
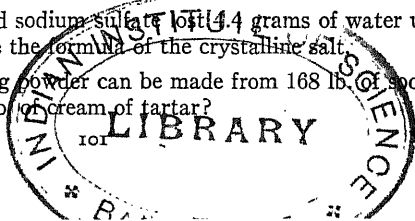
Chem. Prop.
$$\begin{cases} S + O_2 \longrightarrow SO_2 \text{ (Unites with non-metals to form sulfides)} \\ Cu + S \longrightarrow CuS \text{ (Unites with metals to form sulfides)} \\ 2S + Cl_2 \longrightarrow S_2Cl_2 \text{ (Preparation of sulfur chloride)} \\ 4S + 6NaOH + 2H_2O \longrightarrow Na_2S_2O_3 \cdot 5H_2O + 2Na_2S \\ \quad \text{(Prep. of " hypo ")} \end{cases}$$
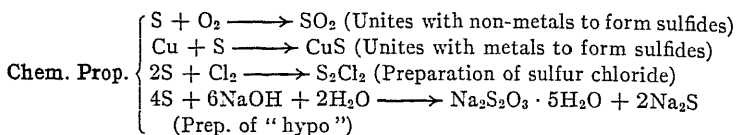
84. What is the percentage of sulfur and carbon present in carbon bisulfide CS_2?

85. It is required to prepare 100 tons of pure hypo. What weight of sulfur is needed to prepare it from sodium hydroxide?

86. What weight of sulfur can be obtained from an ore weighing 120 lb. and containing 87% of FeS_2? What weight of iron could this ore furnish?

87. How many pounds of sulfuric acid can be manufactured from 160 tons of pure sulfur?

88. 95 grams of copper sulfide were obtained by burning 100 grams of copper in sulfur vapor. How much free copper remained after the reaction was completed?

89. On analysis, 18 grams of a compound of iron and sulfur yielded 8.4 grams of iron and the rest of sulfur. What is the simplest formula of this compound?

90. 2 grams of silver sulfide were found on some silverware. How much of the silver was tarnished?

91. With copper selling at $14\frac{1}{2}$¢ per pound and sulfur at $20 per ton what would be the cost of 4000 lb. of copper sulfide, assuming that the cost, excluding chemicals, is 2¢ per pound?

92. How many liters of sulfur dioxide can be formed by burning one kg. of sulfur ore containing 95% of free sulfur? What would be the weight of this oxide?

93. What volume of chlorine will be necessary to prepare 67.5 grams of sulfur chloride?

94. What volumes of sulfur vapor and chlorine gas will be formed when 5 liters of sulfur chloride vapor are completely decomposed into its elements?

95. Assuming that sulfur vapor contains 6 atoms to the molecule, what volume of sulfur vapor will be formed when 116 grams of mercuric sulfide are completely decomposed?

9. HYDROGEN SULFIDE

Lab. Prep. $FeS + 2HCl \longrightarrow FeCl_2 + \uparrow H_2S$ (Action of an acid on a sulfide)

Chem. Prop.
$2H_2S + 3O_2 \longrightarrow 2H_2O + 2SO_2$ (Complete combustion of H_2S)

$2H_2S + O_2 \longrightarrow 2H_2O + \downarrow 2S$ (Incomplete combustion of H_2S)

$2Ag + H_2S \longrightarrow Ag_2S + H_2$ (Tarnishing of silver)

$CuSO_4 + H_2S \longrightarrow \downarrow CuS + H_2SO_4$ (Precipitates metals from their salts)

$Pb(C_2H_3O_2)_2 + H_2S \longrightarrow \downarrow PbS + 2HC_2H_3O_2$ (Test for a sulfide)

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96. The weight of a liter of hydrogen sulfide is 1.54 grams. Find its vapor density, specific gravity, and molecular weight.

97. Which compound contains more sulfur, arsenic sulfide (As_2S_3) or mercuric sulfide (HgS)?

98. A compound of hydrogen and sulfur has a molecular weight of 34. The percentage of sulfur in the compound is 94.11. What is the true formula of this compound?

99. What weight of hydrogen sulfide gas reacted with a copper sulfate solution and precipitated 32 grams of copper sulfide?

100. What was the volume of this hydrogen sulfide gas when measured over water at 17° C. and 765 mm.?

101. A solution containing hydrogen sulfide produced 0.2 gram of lead sulfide when mixed with a lead acetate solution. What was the weight of H_2S present in the solution?

102. How much more lead sulfide will 17 grams of hydrogen sulfide precipitate from a lead nitrate solution, than an equal weight of ammonium sulfide?

103. How much H_2S will be required to combine with all of the zinc in a solution containing 6.8 grams of zinc chloride? What weight of ZnS will be formed?

104. How many grams of ferrous sulfide must be used to prepare 5 liters of hydrogen sulfide gas?

105. What weight of ferrous chloride would be produced in the above reaction?

106. What volume of H_2S is necessary for the complete precipitation of 40 grams of copper sulfate in solution? What will be the weight of this H_2S?

10. SULFUR DIOXIDE

Lab. Prep. $\begin{cases} \text{S} + \text{O}_2 \longrightarrow \text{SO}_2 \text{ (Burning of sulfur)} \\ \text{Na}_2\text{SO}_3 + \text{H}_2\text{SO}_4 \longrightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{O} + \uparrow\text{SO}_2 \text{ (Acid on} \\ \quad \text{a sulfite)} \\ \text{Cu} + 2\text{H}_2\text{SO}_4 \longrightarrow \text{CuSO}_4 + 2\text{H}_2\text{O} + \uparrow\text{SO}_2 \qquad \text{(Conc.} \\ \quad \text{H}_2\text{SO}_4 \text{ on copper)} \end{cases}$

Com. Prep. $4\text{FeS}_2 + 11\text{O}_2 \longrightarrow 2\text{Fe}_2\text{O}_3 + \uparrow 8\text{SO}_2$ (Burning of iron sulfide)

Chem. Prop. $\begin{cases} \text{SO}_2 + \text{H}_2\text{O} \longrightarrow \text{H}_2\text{SO}_3 \text{ (Acid anhydride of sulfurous acid)} \\ 2\text{KMnO}_4 + 5\text{H}_2\text{SO}_3 \longrightarrow \text{K}_2\text{SO}_4 + 2\text{MnSO}_4 + 2\text{H}_2\text{SO}_4 \\ \quad + 3\text{H}_2\text{O} \text{ (Reducing agent)} \end{cases}$

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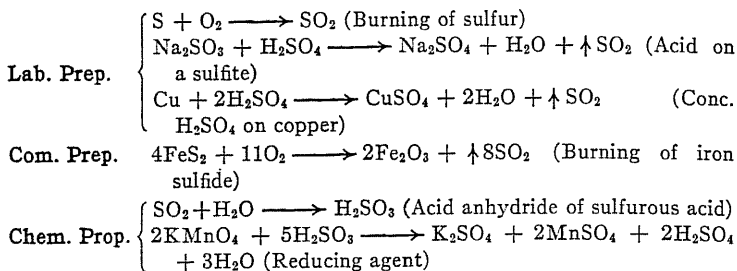
107. The weight of a liter of sulfur dioxide is 2.86 grams. Calculate its vapor density, specific gravity, molecular weight, and the weight of 550 cc. of the gas.

108. How much sodium sulfite must react with sulfuric acid to produce 128 grams of sulfur dioxide?

109. What volume of sulfur vapor containing 4 atoms to the molecule would be used in preparing 2.5 liters of sulfur dioxide gas?

110. What weight of sulfur dioxide is formed by burning 60% of a lot of sulfur weighing 760 kilograms?

111. How much oxygen would be required to oxidize completely 41 grams of sulfurous acid?

112. What weight of copper must react with sulfuric acid to produce 11.1 liters of sulfur dioxide?

113. What volume of sulfur dioxide, measured under standard conditions, can be obtained by burning 1200 kilograms of iron pyrites?

114. What weight of sulfurous acid can be obtained from 5 liters of its anhydride?

115. An unknown weight of potassium sulfite is acted upon by sulfuric acid and 55 cc. of SO_2 is liberated. What weight of the sulfite was decomposed?

116. What volume of air unites with sulfur when the latter is burned to form 100 cc. of sulfur dioxide?

117. It is required to prepare 3.1 lb. of liquid sulfur dioxide. What volume of air (containing 20% oxygen by volume) will be required to synthesize this weight of sulfur dioxide?

118. 500 cu. ft. of sulfur dioxide were liberated during the burning of a load of FeS_2. What weight of this iron compound was roasted during the process?

11. SULFUR TRIOXIDE AND SULFURIC ACID

Com. Prep. (Contact process)
$\begin{cases} 2SO_2 + O_2 \longrightarrow 2SO_3 \text{ (In the presence of Pt catalyst)} \\ H_2SO_4 + SO_3 \longrightarrow H_2SO_4 \cdot SO_3 \text{ (Fuming sulfuric acid)} \\ H_2SO_4 \cdot SO_3 + H_2O \longrightarrow 2H_2SO_4 \quad \text{(Concentrated sulfuric acid)} \end{cases}$

(Chamber process)
$\begin{cases} H_2O + 2SO_2 + N_2O_3 + O_2 \longrightarrow 2SO_2 \cdot OH \cdot ONO \text{ (Nitrosyl sulfuric acid)} \\ 2SO_2 \cdot OH \cdot ONO + H_2O \longrightarrow 2H_2SO_4 + N_2O_3 \end{cases}$

Chem. Prop.
$\begin{cases} Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2 \text{ (Action of concentrated sulfuric acid on copper)} \\ C_{12}H_{22}O_{11} \longrightarrow 11H_2O + 12C \text{ (Dehydrating action)} \\ MnSO_4 + BaCl_2 \longrightarrow \downarrow BaSO_4 + MnCl_2 \text{ (Test for a sulfate)} \end{cases}$

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119. How much sulfur trioxide will be needed to change 490 lb. of sulfuric acid to fuming sulfuric acid?

120. What weight of fuming sulfuric acid can be obtained from 196 grams of sulfuric acid?

121. Calculate the weight of barium sulfate which is formed when a solution containing 52 grams of anhydrous barium chloride is treated with sufficient sulfuric acid.

122. How much sodium chloride must react with sulfuric acid to produce 42.6 grams of dry sodium sulfate?

123. What weight of slaked lime can be neutralized by 98 grams of sulfuric acid?

124. How much zinc sulfate can be formed from 81 grams of zinc oxide?

125. Calculate how many grams of silver sulfate and of copper sulfate could be made from a dime weighing $2\frac{1}{2}$ grams, and containing 10% of copper.

126. The manufacture of sulfuric acid from iron pyrites may be represented by the equation $4FeS_2 + 8H_2O + 15O_2 \longrightarrow 2Fe_2O_3 + 8H_2SO_4$. How much iron pyrites would be required to make 1000 kg. of sulfuric acid?

127. What volume of barium chloride solution containing 61 grams of $BaCl_2 \cdot 2H_2O$ per liter will be required to precipitate all of the sulfate in 10 grams of crystallized ferrous sulfate?

128. How much 68% sulfuric acid (specific gravity = 1.6) can be obtained from one ton of sulfur?

129. How many tons of pyrite containing 40% of available sulfur must be used to make 1000 tons of sulfuric acid, of specific gravity 1.7?

130. How many cubic feet of air are necessary for the conversion of 1000 cubic feet of sulfur dioxide gas to sulfur trioxide?

12. NITROGEN AND THE AIR

Lab. Prep. $\begin{cases} 4P + air (5O_2) \longrightarrow 2P_2O_5 + \text{nitrogen (Impure)} \\ NH_4NO_2 \longrightarrow 2H_2O + N_2 \text{ (Pure)} \end{cases}$

Chem. Prop. $\begin{cases} 3Mg + N_2 \longrightarrow Mg_3N_2 \text{ (Unites with metals to form} \\ \quad \text{nitrides)} \\ N_2 + 3H_2 \longrightarrow 2NH_3 \text{ (Unites with } H_2 \text{ to form ammonia)} \\ 2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O \text{ (Action of NaOH} \\ \quad \text{on } CO_2 \text{ in air)} \\ CaCl_2 + 2H_2O \longrightarrow CaCl_2 \cdot 2H_2O \text{ (Action of } CaCl_2 \text{ on} \\ \quad H_2O \text{ in air)} \end{cases}$
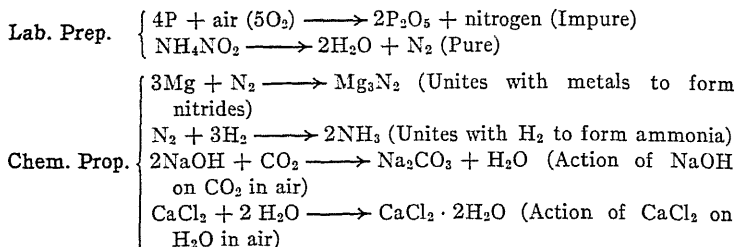
131. What is the percentage of nitrogen in sodium nitrate, $NaNO_3$?

132. The weight of a liter of helium is 0.18 gram. Find its vapor density, specific gravity, molecular weight, and the weight of 5 liters of the gas.

133. Lord Rayleigh, in one of his experiments, obtained 66.5 cc. of argon from 8 liters of air. What is the percentage of argon by volume in the air?

134. Find the true formula of a gas containing 30.4% of nitrogen and the rest of oxygen. A liter of this gas weighs 2.06 grams.

135. If a man inhales 19 cu. ft. of air per hour, what weight of oxygen does he require per day? (Assume that the air contains 20% oxygen by volume. 1 cu. ft. of air weighs 36.5 grams.)

136. Compute the molecular weight of nitrogen from the following data: 222.5 cc. of nitrogen at 12° C. and 760 mm. were found to weigh 0.26 gram.

137. Calculate the weight of air needed to burn 64 grams of sulfur, if the air contained 23.2% of oxygen by weight.

138. What weight of ammonium nitrite must be used to prepare 70 cc. of nitrogen under standard conditions?

139. 500 cc. of nitrogen gas completely unites with burning magnesium. What weight of magnesium nitride is formed?

140. 167 cc. of nitrogen weigh 0.21 gram. Determine the number of atoms in the molecule of nitrogen.

141. What weight of ammonium nitrite would have to be decomposed to furnish 25 cc. of nitrogen gas when measured over water at 17° C. and 760 mm.?

13. AMMONIA AND AMMONIUM HYDROXIDE

Lab. Prep. $(NH_4)_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + \uparrow 2NH_3 + 2H_2O$

Com. Prep. $\begin{cases} N_2 + 3H_2 \longrightarrow 2NH_3 \text{ (Haber process)} \\ CaC_2 + N_2 \longrightarrow CaCN_2 + C \\ CaCN_2 + 3H_2O \longrightarrow CaCO_3 + \uparrow 2NH_3 \end{cases} \begin{array}{l} \\ \text{(Cyanamid} \\ \text{ process)} \end{array}$

Chem. Prop. $\begin{cases} NH_3 + H_2O \longrightarrow NH_4OH \text{ (Its water solution is a base)} \\ 4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O \text{ (Oxidation of ammonia)} \end{cases}$

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142. The specific gravity of ammonia is 0.597. Find its vapor density, molecular weight, and the weight of 1 liter.

143. How many grams of ammonia gas can be obtained from 107 grams of ammonium chloride by heating it with slaked lime?

144. How much oxygen will be required for the complete oxidation of 51 grams of ammonia?

145. 10 grams each of HBr and NH_3 are mixed. What weight of NH_4Br results? What is left over, and what is its volume, measured under standard conditions?

146. 684 grams of ammonium sulfate are heated with sodium hydroxide. What weight of ammonia escapes? What volume?

147. 20 grams of calcium cyanamid are treated with water. How much ammonia, by volume, is produced?

148. Under standard conditions, how many liters of ammonia can be prepared by heating a mixture of 11.4 grams of ammonium sulfate with calcium hydroxide?

149. What weight of ammonium chloride will be formed when 1 liter of ammonia gas comes in contact with 1 liter of hydrogen chloride gas?

150. What weight of pure calcium cyanamid will be needed to prepare 10 liters of ammonia gas?

151. What weight of air, containing 75% of nitrogen by weight, would have to be liquefied to furnish sufficient nitrogen to make 1000 liters of ammonia gas by the Haber process?

152. What volume of nitrogen would be absorbed by 80 grams of calcium carbide in changing the carbide into calcium cyanamid? What weight of carbon will be formed?

153. 100 cc. of dry ammonia are decomposed by electricity. Find the volume of each of the gases formed when measured under standard conditions.

14. OXIDES OF NITROGEN

Lab. Prep.

$$NH_4NO_3 \longrightarrow 2H_2O + \uparrow N_2O \quad (\text{Laughing gas, nitrous oxide})$$

$$3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 4H_2O + 2NO \quad (\text{Nitric oxide})$$

$$2NO + O_2 \longrightarrow 2NO_2 \quad (\text{NO changes to } NO_2 \text{ on exposure to air})$$

Chem. Prop.

$$N_2O_3 + H_2O \longrightarrow 2HNO_2 \quad (N_2O_3 \text{ is the acid anhydride of } HNO_2)$$

$$N_2O_5 + H_2O \longrightarrow 2HNO_3 \quad (N_2O_5 \text{ is the acid anhydride of } HNO_3)$$

$$2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$
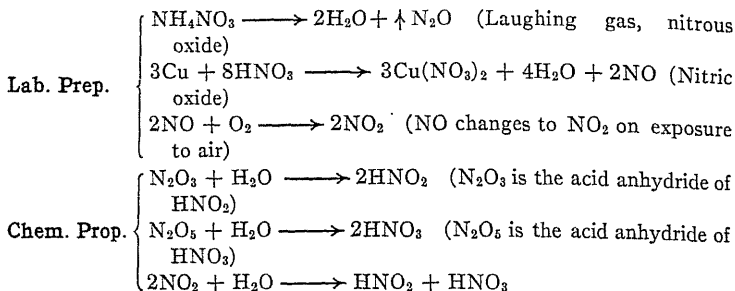
154. The weight of a liter of nitric oxide is 1.32 grams. Find its vapor density, specific gravity, and molecular weight.

155. 290 cc. of nitrous oxide weigh 0.574 gram. Calculate the vapor density, specific gravity, and weight of 1 liter of this gas.

156. What weight of the anhydride can be theoretically obtained from 21 grams of nitric acid?

157. What weight of water will react with 27 lb. of nitric anhydride to form nitric acid?

158. 90 grams of nitric oxide are obtained by the action of copper on nitric acid. How much copper nitrate was formed at the same time?

159. How much nitrous acid (10% by weight) can be made from 19 grams of nitrogen trioxide?

160. What weight of ammonium nitrate must be heated to produce 5 liters of laughing gas?

161. 5 grams of copper are completely dissolved in nitric acid. What volume of nitric oxide is liberated, the gas being measured at standard conditions?

162. 53 cc. of nitric oxide are liberated in a reaction and the gas is then exposed to the air. What volume of oxygen combined with the nitric oxide, and what weight of nitrogen peroxide was produced?

163. What weight of ammonium nitrate must be decomposed to fill a balloon of 100 liters' capacity when measured at 25° C. and 760 mm. pressure, with laughing gas?

164. How many cubic centimeters of air are necessary to change completely 65 cc. of nitric oxide to the peroxide?

165. 5 liters of laughing gas are decomposed into its elements. What volumes of the products are formed?

15. NITRIC ACID AND AQUA REGIA

Lab. Prep. $NaNO_3 + H_2SO_4 \longrightarrow NaHSO_4 + HNO_3$ (Action of H_2SO_4 on a nitrate)

Com. Prep. $2NaNO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + 2HNO_3$ (Same as lab. prep.)

Chem. Prop. $\begin{cases} Cu + 4HNO_3 \longrightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2 \quad \text{(Conc.} \\ \quad HNO_3 \text{ used)} \\ 3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O \quad \text{(Cold} \\ \quad \text{dil. } HNO_3 \text{ used)} \\ 3HCl + HNO_3 \longrightarrow 2H_2O + NO + 3Cl \text{ (Action of aqua} \\ \quad \text{regia)} \\ Au + 3Cl \longrightarrow AuCl_3 \text{ (Action of aqua regia on gold)} \end{cases}$

166. How many grams of nitric acid can be obtained by heating 425 grams of sodium nitrate with sulfuric acid?

167. What weight of gold will be dissolved by aqua regia capable of furnishing 142 grams of nascent chlorine?

168. Chile saltpeter, containing 12% impurities, is treated with 49 lb. of sulfuric acid. What weight of nitric acid will be produced?

169. 20 grams of sodium bisulfate ($NaHSO_4$) were produced by the action of sodium nitrate and sulfuric acid. What weight of nitric acid was produced at the same time?

170. 189 grams of concentrated nitric acid reacted with an excess of copper. What volume of nitrogen peroxide was liberated?

171. What weight of 65% nitric acid should be taken just to dissolve 27 grams of silver?

172. What volume of nitrogen peroxide can be obtained by the action of 32 grams of copper on concentrated nitric acid?

173. What weight of commercial potassium hydroxide, containing 10% water, can be neutralized by 105 grams of 50% HNO_3 (Sp. Gr., 1.315)?

174. Gold is dissolved in aqua regia and 5.3 grams of gold chloride are formed. How much chlorine, by volume, was furnished by the aqua regia?

175. 2.7 grams of silver are dissolved in nitric acid. The resulting silver nitrate is treated with a solution of sodium chloride. What weight of silver chloride is precipitated?

176. Nitric acid, containing 50% by weight of HNO_3, is sold for $5 per 100 lb. What would be the cost of neutralizing 5 tons of slaked lime ($Ca(OH)_2$) with this acid?

177. What weight of aqua regia will be needed to dissolve completely 5.3 grams of gold? Assume the use of 100% acids.

16. NITRATES AND NITROGEN FIXATION

Com. Fixation of N :
$$\begin{cases} N_2 + O_2 \longrightarrow 2NO \\ 2NO + O_2 \longrightarrow 2NO_2 \\ 2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3 \end{cases} \text{(Arc process)}$$
$$\begin{cases} CaC_2 + N_2 \longrightarrow CaCN_2 + C \\ CaCN_2 + 3H_2O \longrightarrow 2NH_3 + CaCO_3 \end{cases} \begin{matrix}\text{(Cyanamid} \\ \text{process)}\end{matrix}$$
$$N_2 + 3H_2 \longrightarrow 2NH_3 \qquad \text{(Haber process)}$$

Chem. Prop.
$$\begin{cases} NaNO_3 + KCl \longrightarrow NaCl + KNO_3 \text{ (Prep. of } KNO_3) \\ 2KNO_3 + 3C + S \longrightarrow K_2S + 3CO_2 + N_2 \text{ (Explosion of} \\ \quad \text{gunpowder)} \end{cases}$$

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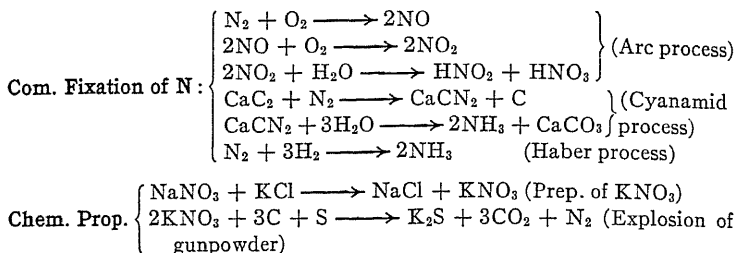
178. Calculate the percentage of nitrogen present in nitroglycerine, whose formula is $C_3H_5(NO_3)_3$.

179. What weight of saltpeter (KNO_3) can be formed from 170 lb. of impure Chile saltpeter containing 90% $NaNO_3$?

180. 1.49 grams of potassium chloride in solution are treated with a solution of sodium nitrate. What weight of potassium nitrate is theoretically possible?

181. What weight of ammonia can be produced from 1 kilogram of cyanamid containing only 90% $CaCN_2$?

182. 50.5 lb. of KNO_3 are used in the making of gunpowder. What weights of sulfur and carbon must be added to the potassium nitrate?

183. The gunpowder in the above problem was exploded. The temperature attained by the reaction was 2000° C. What volume of CO_2 was liberated?

184. A volume of nitric oxide is exposed to the air and 52 cc. of nitrogen peroxide are formed. How much NO was originally present (the gas being measured under standard conditions)?

185. How many liters of nitric oxide can be obtained by oxidizing 500 cc. of ammonia gas?

186. What weight of calcium carbide will be needed to furnish enough calcium cyanamid to give 5 liters of ammonia?

187. 5 liters of air, containing 78% nitrogen and 21% oxygen by volume, are treated with an electric spark. What volume of nitric oxide would be formed if the reaction were not reversible?

17. PHOSPHORUS

Com. Prep. $\begin{cases} Ca_3(PO_4)_2 + 3SiO_2 + 5C \longrightarrow 3CaSiO_3 + 5CO + \uparrow 2P \\ \text{(In electric furnace)} \\ Ca_3(PO_4)_2 + 2H_2SO_4 + 2H_2O \longrightarrow \\ \qquad 2CaSO_4 + CaH_4(PO_4)_2 \cdot 2H_2O \text{ (Superphosphate)} \end{cases}$

Chem. Prop. $\begin{cases} 4P + 3O_2 \longrightarrow 2P_2O_3 \text{ (Incomplete oxidation of P)} \\ 4P + 5O_2 \longrightarrow 2P_2O_5 \text{ (Complete combustion of P)} \\ P_2O_5 + 3H_2O \longrightarrow 2H_3PO_4 \text{ (Acid anhydride of phos-} \\ \qquad \text{phoric acid)} \\ Ca_3P_2 + 6H_2O \longrightarrow 3Ca(OH)_2 + \uparrow 2PH_3 \qquad \text{(Preparation} \\ \qquad \text{of phosphine)} \end{cases}$

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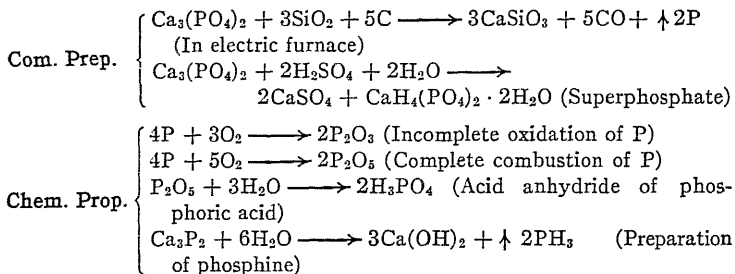
188. What is the percentage composition of disodium acid phosphate (Na_2HPO_4)?

189. What is the percentage of phosphorus in Thomas slag whose composition might be considered to be $(CaO)_5 \cdot P_2O_5 \cdot SiO_2$?

190. A compound was vaporized and its vapor density was found to be 76.9. It contained 22.7% phosphorus, 10.9% oxygen, and 66.4% chlorine. Find the true formula of this compound.

191. What weight of oxygen will be consumed in combining with 0.62 gram of phosphorus?

192. Calculate the amount of phosphorus available in a skeleton weighing 20 lb. and containing 70% calcium phosphate.

193. One pound of phosphorus serves to tip one million matches. How many matches can be tipped from the phosphorus obtained from a human skeleton weighing 20 lb. and containing 50% $Ca_3(PO_4)_2$?

194. The price of phosphorus in the New York market is 68¢ per pound. What is the value of the phosphorus found in a human skeleton which weighs 25 lb. and contains 60% of calcium phosphate?

195. How much superphosphate can be prepared from 1500 lb. of bones containing 75% calcium phosphate? What weight of $CaSO_4$ is formed at the same time?

196. What weight of water is necessary for the complete hydrolysis of 27.5 grams of phosphorus trichloride? $PCl_3 + 3H_2O \longrightarrow H_3PO_3 + 3HCl$.

197. 5.5 liters of phosphine were liberated by the action of calcium phosphide and water. What weight of $Ca(OH)_2$ was formed at the same time?

18. ARSENIC, ANTIMONY, AND BISMUTH

Com. Prep.
$$\begin{cases} 2As_2S_3 + 9O_2 \longrightarrow 2As_2O_3 + 6SO_2 \quad \text{(Roasting of the sulfide)} \\ As_2O_3 + 3C \longrightarrow 2As + 3CO \quad \text{(Reduction of the oxide)} \\ Sb_2S_3 + 3Fe \longrightarrow 2Sb + 3FeS \quad \text{(Action of Fe on the sulfide)} \end{cases}$$

Chem. Prop.
$$\begin{cases} AsCl_3 + 3H_2 \longrightarrow \uparrow AsH_3 + 3HCl \quad \text{(Formation of arsine)} \\ 2AsH_3 + 3O_2 \longrightarrow 3H_2O + As_2O_3 \quad \text{(Marsh's test for arsenic)} \\ 2SbCl_3 + 3H_2S \longrightarrow \downarrow Sb_2S_3 + 6HCl \quad \text{(Precipitation of } Sb_2S_3) \end{cases}$$

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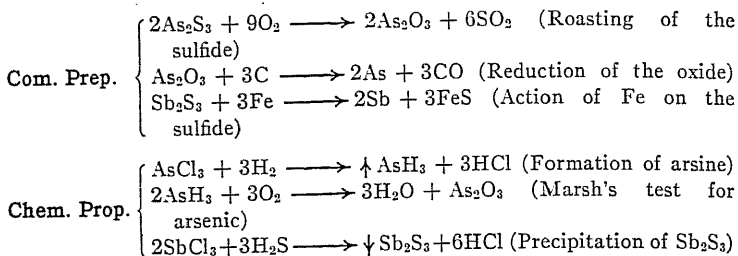
198. Mispickel (FeAsS), orpiment (As_2S_3), realgar (As_2S_2), and white arsenic (As_2O_3) are the principal ores of arsenic. Determine the percentage of arsenic in each.

199. What volume of carbon monoxide will be formed in the reduction of 33 grams of As_2O_3 by carbon?

200. What volume of hydrogen will be needed to prepare 5.5 liters of arsine from $AsCl_3$?

201. A compound contains 96.2% arsenic and 3.8% hydrogen. What is its true formula if the vapor density of the compound is found to be 38.9?

202. Wood's metal consists of Bi 4 parts, Pb 2 parts, Sn 1 part, and Cd 1 part. How much bismuth is necessary to make 10 lb. of this easily fusible alloy?

203. What weight of iron will be required to extract completely all the antimony from 42 lb. of antimony trisulfide?

204. Wood's metal is composed of 50% bismuth, 12.5% each of tin and cadmium, and 25% lead. What weight of lead oxide, PbO, would have to be reduced to furnish sufficient lead to make 100 lb. of Wood's metal?

205. The stomach of a poison victim was analyzed and 1.5 grams of arsenic were found. How much Paris green, $Cu(C_2H_3O_2)_2 \cdot Cu_3(AsO_3)_2$, was swallowed by the victim?

206. 55 grams of bismuth formed 61.4 grams of Bi_2O_3. What is the atomic weight of this element?

19. BROMINE AND HYDROBROMIC ACID

Lab. Prep.
$$\begin{cases} 2KBr + MnO_2 + 2H_2SO_4 \longrightarrow \\ \qquad\qquad\qquad K_2SO_4 + MnSO_4 + 2H_2O + \uparrow Br_2 \\ 2KBr + H_2SO_4 \longrightarrow K_2SO_4 + 2HBr \text{ (Impure)} \\ PBr_3 + 3H_2O \longrightarrow H_3PO_3 + 3HBr \text{ (Pure)} \end{cases}$$

Com. Prep.　　$MgBr_2 + Cl_2 \longrightarrow MgCl_2 + Br_2$

Chem. Prop. $\begin{cases} 2KBr + Cl_2 \longrightarrow 2KCl + Br_2 \text{ (Replacement)} \\ 2KBr + 2H_2SO_4 \longrightarrow K_2SO_4 + 2H_2O + SO_2 + Br_2 \end{cases}$

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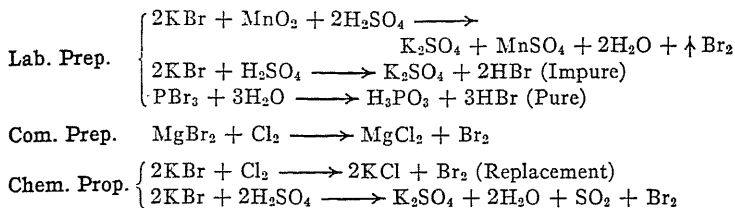
207. A liter of bromine gas weighs 7.2 grams. What are its vapor density, specific gravity, and molecular weight?

208. How much sodium bromide must be heated with sulfuric acid and manganese dioxide to obtain 10 grams of bromine?

209. In the preparation of bromine 48 grams of manganese sulfate were found among the products of the reaction. What weight of potassium salt was decomposed?

210. 238 lb. of potassium bromide are treated with sufficient sulfuric acid to decompose it completely. What weight of hydrogen bromide will be formed?

211. 0.35 part of magnesium bromide was found in 1000 parts of sea water. How much of this water would be required to furnish 10 lb. of bromine?

212. What weight of phosphorus tribromide will be needed to prepare 162 kilograms of pure HBr?

213. A solution of sodium bromide was treated with an excess of silver nitrate and 0.6 gram of silver bromide was precipitated. What weight of NaBr was present in the original solution?

214. What weight of manganese dioxide must be used to obtain 1 liter of bromine vapor from KBr?

215. Chlorine gas is passed through a solution of potassium bromide until 5 grams of bromine are liberated. What weight of the bromide was decomposed? What volume would this bromine occupy at 57° C.?

216. 45 grams of magnesium chloride were obtained from a bromide. What volume of chlorine, measured at 20° C. and 760 mm., took part in the reaction?

20. IODINE AND HYDROGEN IODIDE

Lab. Prep.
$$\begin{cases} 2KI + MnO_2 + 2H_2SO_4 \longrightarrow \\ \qquad\qquad K_2SO_4 + MnSO_4 + 2H_2O + I_2 \\ PI_3 + 3H_2O \longrightarrow H_3PO_3 + 3HI \text{ (Pure)} \end{cases}$$

Com. Prep. $2NaIO_3 + 3Na_2SO_3 + 2NaHSO_3 \longrightarrow$
$$5Na_2SO_4 + H_2O + I_2$$

Chem. Prop.
$$\begin{cases} 2Na_2S_2O_3 + I_2 \longrightarrow 2NaI + Na_2S_4O_6 \text{ (Soluble in hypo)} \\ 2KI + Br_2 \longrightarrow 2KBr + I_2 \text{ (Replacement)} \\ H_2S + I_2 \longrightarrow 2HI + S \quad (I_2 \text{ is a mild oxidizing agent)} \end{cases}$$

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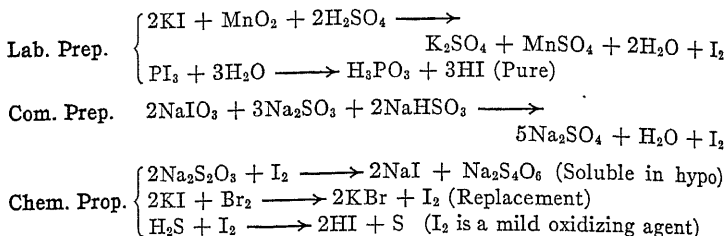
217. 90 cc. of hydrogen iodide gas weigh 0.516 gram. Calculate its vapor density, specific gravity, weight of a liter, and molecular weight.

218. Find the molecular weight of hydrogen iodide if the specific gravity of the compound is 4.42.

219. A compound contains 96.7% iodine, 3.05% carbon, and 0.25% hydrogen. Its vapor density is 197. Find the true formula of this compound.

220. How much potassium iodide is needed to prepare 63.5 grams of iodine?

221. How much iodoform, CHI_3, can be obtained from 1 kg. of iodine?

222. How much sulfuric acid must be used to obtain all the iodine available in 83 lb. of potassium iodide?

223. Which will liberate more free iodine from an ammonium iodide solution — 50 grams of chlorine or 100 grams of bromine?

224. A ton of kelp will give 2 lb. of iodine. How much potassium iodide can be prepared from the iodine available in 10.5 tons of this kelp?

225. How much free iodine is necessary to oxidize 1 gram of hypo? (The crystal contains 5 molecules of water of crystallization.)

226. What volume of chlorine gas must be used just to liberate all the iodine in a liter of potassium iodide solution containing 33.2 grams of the salt?

227. How much phosphorus tri-iodide must be reacted with water to produce 500 cc. of hydrogen iodide gas?

228. What volume of bromine vapor must be passed through a sodium iodide solution to precipitate 3.81 grams of iodine?

21. FLUORINE AND ETCHING OF GLASS BY HYDROGEN FLUORIDE

Lab. Prep. $CaF_2 + H_2SO_4 \longrightarrow CaSO_4 + \uparrow 2HF$ (The common preparation is the same)

Chem. Prop.
$\begin{cases}
SiO_2 + 4HF \longrightarrow \uparrow SiF_4 + 2H_2O \text{ (Etching of glass)} \\
3F_2 + 3H_2O \longrightarrow 6HF + O_3 \text{ (Action of } F_2 \text{ on water)} \\
CaSiO_3 + 6HF \longrightarrow \uparrow SiF_4 + CaF_2 + 3H_2O \text{ (Action of} \\
\quad HF \text{ on insoluble silicates)}
\end{cases}$

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229. What is the percentage of fluorine in cryolite, Na_3AlF_6, and in fluorite, CaF_2?

230. Determine the percentage composition of $(NaF)_3 \cdot AlF_3$ both by elements and salts.

231. A liter of silicon fluoride weighs 4.68 grams. Calculate the molecular weight, vapor density, and specific gravity of this vapor.

232. A quantity of fluor-spar is treated with sulfuric acid, and, as a result, 3.4 grams of calcium sulfate is obtained. What weight of fluor-spar was decomposed?

233. What weight of quartz will a liter of hydrofluoric acid, containing 30% HF by weight, dissolve? (Sp. Gr. of 30% HF is 1.12.)

234. Assuming the formula for glass to be $CaO \cdot Na_2O \cdot 6SiO_2$, what weight of HF would be required to etch away 28.9 grams of this glass?

235. What weight of calcium fluoride must be used to prepare 5 liters of hydrogen fluoride gas?

236. 5 liters of hydrogen fluoride were liberated when sulfuric acid reacted with fluor-spar. What weight of calcium sulfate was prepared at the same time?

237. What volume of hydrogen fluoride gas is needed to reduce the weight of a glass plate 2 grams? The formula for glass is taken as $CaO \cdot Na_2O \cdot 6SiO_2$.

238. What weight of hydrogen fluoride would be required to react with quartz to furnish 5 liters of silicon fluoride?

239. What volume of fluorine must react with water to produce 500 cc. of hydrogen fluoride gas? What volume of ozone will be formed at the same time?

22. ALLOTROPIC FORMS AND VARIETIES OF CARBON

Lab. Prep. $C_{12}H_{22}O_{11} \longrightarrow 11H_2O + 12C$ (Pure carbon from cane sugar)

Chem. Prop.
$\begin{cases} C + O_2 \longrightarrow CO_2 \text{ (Complete combustion of carbon)} \\ 2C + O_2 \longrightarrow 2CO \text{ (Incomplete combustion of carbon)} \\ C + CuO \longrightarrow Cu + CO \text{ (Carbon a reducing agent)} \\ C + CO_2 \longrightarrow 2CO \text{ (Reduction of } CO_2 \text{ by C)} \\ C + H_2O \longrightarrow CO + H_2 \text{ (Prep. of water gas)} \end{cases}$

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240. 171 lb. of dry cane sugar are treated with concentrated sulfuric acid. What weight of pure carbon will result?

241. How much steam, by weight and volume, can react with 120 grams of pure carbon?

242. A manufacturer requires 6 lb. of pure carbon made from cane sugar. What weight of the latter would have to be decomposed to supply this weight of pure carbon?

243. What weight of coke containing 90% carbon would be needed to reduce 10 tons of hematite containing 85% Fe_2O_3?

244. 5 grams of coke, on burning in a sufficient supply of oxygen, gave 17 grams of carbon dioxide. Find the percentage of carbon in the coke.

245. Determine the volume of gas, measured at standard conditions, which can be obtained by the complete combustion of 12 grams of pure carbon.

246. What volume of air would be required for the complete combustion of 1 kg. of coal containing 80% of carbon?

247. Calculate the weight of air necessary to burn a ton of coal containing 90% carbon. Air contains 23% of oxygen by weight.

248. What weight of hematite, containing 79% of Fe_2O_3, can be reduced by 1000 lb. of coke, containing 98% pure carbon?

249. Carbon monoxide was passed over hot copper oxide. 134 grams of carbon dioxide were formed, and 48.7 grams of oxygen were lost by the copper oxide. Determine the atomic weight of carbon from these data.

250. An organic compound was completely oxidized and the carbon dioxide formed was absorbed, and found to weigh 5.3 grams. What weight of carbon did the organic compound contain?

23. CARBON DIOXIDE AND CARBONIC ACID

Lab. Prep. $\begin{cases} CaCO_3 + 2HCl \longrightarrow CaCl_2 + \uparrow CO_2 + H_2O \text{ (Acid on a carbonate)} \\ C + O_2 \longrightarrow CO_2 \text{ (Complete combustion of carbon)} \end{cases}$

Chem. Prop. $\begin{cases} CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (Acid anhydride of carbonic acid)} \\ 6CO_2 + 5H_2O \longrightarrow C_6H_{10}O_5 + \uparrow 6O_2 \text{ (Photosynthesis)} \\ NaHCO_3 + HKC_4H_4O_6 \longrightarrow NaKC_4H_4O_6 + H_2O + \uparrow CO_2 \\ \quad \text{(Action of baking powder)} \\ H_2CO_3 + CaCO_3 \longrightarrow Ca(HCO_3)_2 \end{cases}$

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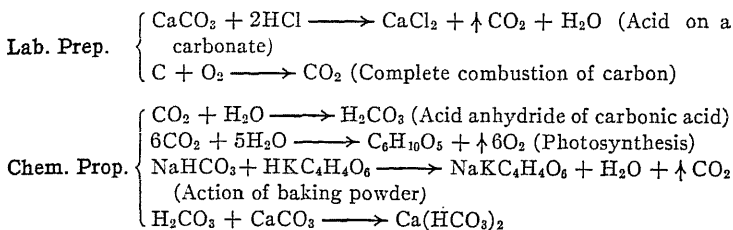
251. What percentage of carbon, by weight, is contained in carbon dioxide and carbon monoxide?

252. The weight of a liter of carbon dioxide is 1.98. Find its vapor density, specific gravity, molecular weight, and the weight of 275.75 cc. of the gas.

253. How many grams of pure calcium carbonate must be used to prepare 22 grams of carbon dioxide by the action of hydrochloric acid.

254. 25 grams of marble, containing 5% of inert material, are dissolved in hydrochloric acid. Calculate the weights of the substances formed.

255. How many grams of sulfuric acid reacting with an excess of sodium carbonate will be required to form 220 grams of carbon dioxide?

256. What weight of carbon dioxide will be required to precipitate the calcium in 3.7 grams of calcium hydroxide, as calcium carbonate?

257. What weight of carbon dioxide will be used to change limewater into 81 grams of calcium bicarbonate?

258. If a piece of pure graphite weighing 1 kg. is burned in oxygen, what volume of carbon dioxide will be produced?

259. What weight of starch can a plant manufacture from 20 liters of carbon dioxide gas?

260. What volume of oxygen is liberated in this reaction?

261. Calculate the weights of sodium bicarbonate and cream of tartar found in 100 grams of baking powder. What volume of carbon dioxide can this baking powder liberate?

24. CARBON MONOXIDE

Lab. Prep. $\begin{cases} HCOOH \longrightarrow CO + H_2O \text{ (Decomposition of formic acid)} \\ COOH \cdot COOH \longrightarrow CO + CO_2 + H_2O \text{ (Oxalic acid and} \\ \quad \text{concentrated } H_2SO_4) \end{cases}$

Com. Prep. $\begin{cases} H_2O + C \longrightarrow H_2 + CO \text{ (Production of water gas)} \\ CO_2 + C \longrightarrow 2CO \text{ (Reduction of } CO_2) \end{cases}$

Chem. Prop. $\begin{cases} 2CO + O_2 \longrightarrow 2CO_2 \text{ (Combustion of carbon monoxide)} \\ CO + Cl_2 \longrightarrow COCl_2 \text{ (Formation of phosgene)} \end{cases}$

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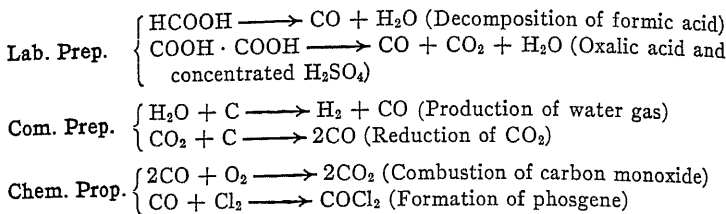
262. The weight of a liter of carbon monoxide is 1.25. Calculate its vapor density, specific gravity, and molecular weight.

263. The specific gravity of carbon monoxide is 0.968. Calculate its molecular weight.

264. A gas contains 43% carbon and 57% oxygen. 33 cc. of this gas weigh 0.042 gram. Calculate the true formula of the compound from these data.

265. 20 grams of carbon are heated in the presence of 88 grams of carbon dioxide. What weight of carbon monoxide is formed? What weight, if any, of carbon remains?

266. What volume of carbon dioxide must be passed over glowing charcoal to form 42 grams of carbon monoxide?

267. 108 lb. of steam are passed over glowing coal. What volume of carbon monoxide will the resulting water gas contain?

268. 25 cc. of carbon monoxide were prepared from formic acid. What weight of the acid was decomposed?

269. What weight of coke, containing 95% carbon, will be needed to reduce completely 3.5 liters of carbon dioxide gas?

270. What weight of formic acid will be needed to liberate 100 cc. of carbon monoxide measured under standard conditions?

271. What volume of oxygen is required for the combustion of 10 cu. ft. of carbon monoxide?

272. 0.442 gram of phosgene gas occupies 100 cc. Determine its molecular weight, specific gravity, vapor density, and the weight of 9 liters.

25. ILLUMINATING GAS, WATER GAS, AND PRODUCER GAS

Com. Prep. $\begin{cases} H_2O + C \longrightarrow H_2 + CO \text{ (Water gas)} \\ 2C + \text{air } (N_2 + O_2) \longrightarrow 2CO + N_2 \text{ (Producer gas)} \end{cases}$

Chem. Prop. $\begin{cases} 2CO + O_2 \longrightarrow 2CO_2 \text{ (Burning of carbon monoxide)} \\ 2CO + 2H_2 + 2O_2 \longrightarrow 2CO_2 + 2H_2O \text{ (Burning of water} \\ \text{gas)} \end{cases}$

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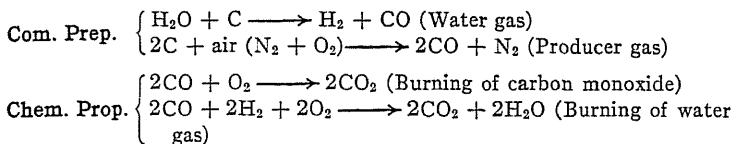
273. What volume of steam is required for the production of 1000 liters of water gas?

274. Water gas contains 40% of hydrogen and 60% of carbon monoxide by volume. What volume of air is necessary for the complete combustion of 1000 cu. ft. of such a gas? (Assume air to contain 20% oxygen by volume.)

275. What weight of coal is required to produce 1000 cu. ft. of water gas? (*Note.* The molecular weight of a substance expressed in ounces occupies 22.2 cu. ft.)

276. Analysis of a producer gas showed the presence of 30% of carbon monoxide. How much carbon was burned in preparing 1000 cu. ft. of this fuel?

277. 10 grams of carbon were treated with steam, and water gas was produced. The water gas thus obtained was completely burned to carbon dioxide and water vapor. What volumes of these gases were formed?

278. What weight of glowing coal, containing only 95% carbon, would have to be treated with steam in order to make 10,000 cu. ft. of water gas?

279. 5 liters of producer gas containing 27% carbon monoxide were burned as fuel. What weight and what volume of carbon dioxide were produced?

280. A kilogram of glowing carbon was treated with steam and the resulting water gas was burned in oxygen. Determine the volume of carbon dioxide produced.

281. A natural gas from the Pittsburgh region contained 26% hydrogen and 65% methane (CH_4). What weight of water would be formed in completely burning 500 liters of this gas?

26. REACTIONS WITH CARBON IN THE ELECTRIC FURNACE

Com. Prep.
$\begin{cases} CaO + 3C \longrightarrow CaC_2 + CO \quad \text{(Preparation of calcium carbide)} \\ SiO_2 + 3C \longrightarrow SiC + 2CO \text{ (Preparation of carborundum)} \\ C + 2S \longrightarrow CS_2 \text{ (Preparation of carbon disulfide)} \end{cases}$

Chem. Prop.
$\begin{cases} CaC_2 + 2H_2O \longrightarrow \uparrow C_2H_2 + Ca(OH)_2 \text{ (Action of } CaC_2 \text{ on water)} \\ CS_2 + 3O_2 \longrightarrow CO_2 + 2SO_2 \text{ (Complete combustion of } CS_2) \\ CS_2 + O_2 \longrightarrow CO_2 + 2S \text{ (Incomplete combustion of } CS_2) \end{cases}$

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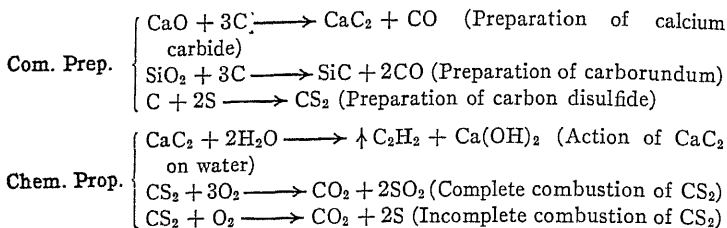
282. What weight of carbon bisulfide can be produced from 3000 lb. of sulfur?

283. How much carborundum can be made theoretically from a ton of sand composed of 90% SiO_2?

284. Assuming that 75% of the carbon is converted into carborundum, what weight of carbon will be needed in the production of 5 tons of silicon carbide?

285. How much sand containing 5% impurities must be used to obtain a theoretical yield of 5 tons of carborundum?

286. What weight of sulfur will be formed by the incomplete combustion of 38 grams of carbon bisulfide?

287. 500 cc. of the vapor of carbon disulfide weigh 1.71 grams. Calculate its vapor density, specific gravity, molecular weight, and the weight of 35 cc.

288. What weight of sulfur will be produced in the incomplete combustion of 350 cc. of carbon bisulfide vapor?

289. What weights of the elements must be combined to produce 5 liters of carbon bisulfide vapor?

290. How much dry calcium carbide will be needed to produce 510 cc. of acetylene gas?

291. What amount of calcium oxide must be used to make sufficient calcium carbide to furnish 5000 liters of acetylene gas, measured under standard conditions?

292. What volume of sulfur dioxide is produced in the complete combustion of 50 cc. of carbon bisulfide vapor?

293. What weight of calcium carbide must be used in order to fill an acetylene reservoir holding 25 liters of the gas at 17° C. and 760 mm. pressure?

27. SILICON DIOXIDE, GLASS, AND BORAX

Chem. Prop.
$\begin{cases}
\text{SiO}_2 + 2\text{KOH} \longrightarrow \text{K}_2\text{SiO}_3 + \text{H}_2\text{O} \quad (\text{SiO}_2 \text{ reacts with bases, forming silicates}) \\
\text{SiO}_2 + 2\text{NaOH} \longrightarrow \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O} \quad (\text{Preparation of water glass}) \\
\text{SiO}_2 + \text{H}_2\text{O} \longrightarrow \text{H}_2\text{SiO}_3 \quad (\text{SiO}_2 \text{ the acid anhydride of silicic acid}) \\
\text{Na}_2\text{CO}_3 + \text{CaCO}_3 + 6\text{SiO}_2 \longrightarrow \text{Na}_2\text{O} \cdot \text{CaO} \cdot 6\text{SiO}_2 + 2\text{CO}_2 \quad (\text{Formation of glass}) \\
\text{SiCl}_4 + 4\text{H}_2\text{O} \longrightarrow 4\text{HCl} + \text{Si(OH)}_4 \quad (\text{Action of SiCl}_4 \text{ on water}) \\
\text{Na}_2\text{B}_4\text{O}_7 + \text{H}_2\text{SO}_4 + 5\text{H}_2\text{O} \longrightarrow \text{Na}_2\text{SO}_4 + 4\text{H}_3\text{BO}_3 \quad (\text{Boric acid from borax})
\end{cases}$

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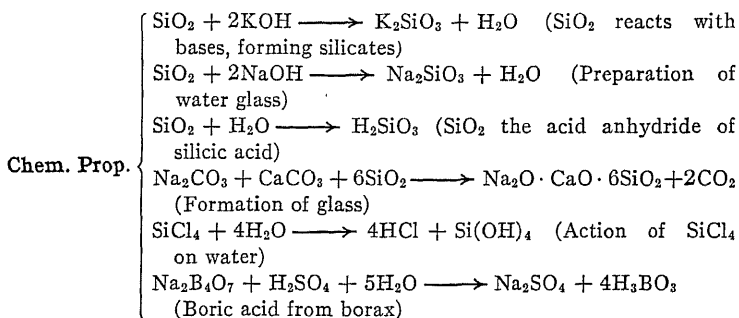
294. What percentage by weight does crystallized borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) lose on being heated until it has lost all of its water of crystallization?

295. How much of the element boron is present in 5 grams of anhydrous borax?

296. Find the percentage of silicon in the following silicates: talc [$\text{H}_2\text{Mg}_3(\text{SiO}_3)_4$] and clay [$\text{H}_2\text{Al}_2(\text{SiO}_4)_2 \cdot \text{H}_2\text{O}$].

297. A compound contains 29.2% silicon, 66.7% oxygen, and 4.10% hydrogen. Find the simplest formula of this compound.

298. How much commercial NaOH containing 10% water would have to be used to prepare 244 grams of water glass?

299. When 39 grams of silicic acid are dehydrated, what weight of silicon dioxide remains?

300. How much calcium oxide would have to be used as flux in order to remove 60 kg. of SiO_2 present in an ore? How much slag would result?

301. The reaction representing the formation of glass may be represented by the above equation (4). What weights of materials must be used to make 100 kg. of glass?

302. Find the weights of materials necessary to make 1000 lb. of potassium lead glass.

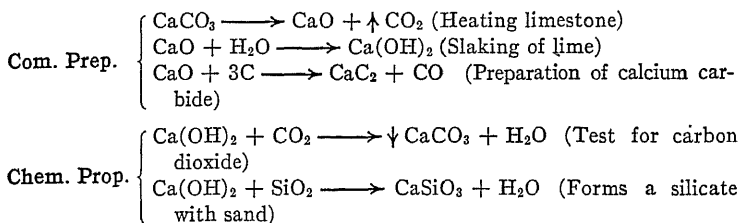303. What weight of sulfuric acid would be required to convert 100 tons of sodium borate, containing 20% impurities, to boric acid, H_3BO_3?

28. CALCIUM, CALCIUM CARBONATE, AND HARD WATER

Com. Prep. $CaCl_2 \longrightarrow Ca + Cl_2$ (Electrolysis of fused $CaCl_2$)

Chem. Prop.
$\left\{\begin{array}{l} Ca(OH)_2 + CO_2 \longrightarrow \downarrow CaCO_3 + H_2O \quad \text{(Formation of insoluble } CaCO_3) \\ CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2 \quad \text{(Formation of soluble } Ca(HCO_3)_2) \\ CaSO_4 + Na_2CO_3 \longrightarrow \downarrow CaCO_3 + Na_2SO_4 \quad \text{(Softening of permanent hard water)} \\ Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow \downarrow 2CaCO_3 + 2H_2O \quad \text{(Softening of temporary hard water)} \\ 2C_{17}H_{35}COONa + CaSO_4 \longrightarrow Na_2SO_4 + \downarrow (C_{17}H_{35}COO)_2Ca \\ \text{(Action of hard water on soap)} \end{array}\right.$

304. Determine the simplest formula of a compound containing 40.1% calcium, 12% carbon, and 47.9% oxygen. The molecular weight of this compound is 100. What is its true formula?

305. What weight of calcium chloride must be decomposed to produce 5 grams of pure calcium?

306. What volume of chlorine, measured under standard conditions, would be liberated in the above operation?

307. What weight of water would be required to dissolve completely 15 grams of calcium? What weight of calcium hydroxide would be formed?

308. How much slaked lime, containing 90% $Ca(OH)_2$, will be needed to precipitate completely a solution containing 243 grams of the bicarbonate of magnesium?

309. What volume of carbon dioxide is liberated when 48.6 grams of calcium bicarbonate are heated?

310. What weight of potassium stearate, $C_{17}H_{35}COOK$, would be required to precipitate 5 grams of magnesium sulfate dissolved in 100 liters of water?

311. If 100 grams of $BaCl_2$ give 112.1 grams of barium sulfate, find the atomic weight of barium.

312. A water contains 1.2 grams of calcium bicarbonate per gallon. What weight of calcium hydroxide would be required to soften 1000 gal. of this water?

313. 100 grams of $CaCl_2 \cdot 2H_2O$ and 69 grams of K_2CO_3 are mixed in solution. Calculate the weights of calcium and potassium salts in filtrate and precipitate.

29. CALCIUM OXIDE AND CALCIUM HYDROXIDE

Com. Prep.
$$\begin{cases} CaCO_3 \longrightarrow CaO + \uparrow CO_2 \text{ (Heating limestone)} \\ CaO + H_2O \longrightarrow Ca(OH)_2 \text{ (Slaking of lime)} \\ CaO + 3C \longrightarrow CaC_2 + CO \quad \text{(Preparation of calcium carbide)} \end{cases}$$

Chem. Prop.
$$\begin{cases} Ca(OH)_2 + CO_2 \longrightarrow \downarrow CaCO_3 + H_2O \quad \text{(Test for carbon dioxide)} \\ Ca(OH)_2 + SiO_2 \longrightarrow CaSiO_3 + H_2O \quad \text{(Forms a silicate with sand)} \end{cases}$$

314. How many tons of lime can be made from 100 tons of limestone, containing 90% $CaCo_3$?

315. How many pounds of calcium carbide can be made theoretically from a long ton of lime?

316. What weight of water will be necessary to slake completely 28 lb. of quicklime?

317. How many pailfuls of water, each pail having a capacity of 50 lb. of water, will be necessary to slake completely a ton of quicklime?

318. 2 tons of water are just sufficient to slake a load of lime. The lime is made into mortar, which is then used in plastering a house. What weight of carbon dioxide may be chemically absorbed by the mortar?

319. What weight of lime containing 80% CaO will be required to make 128 lb. of calcium carbide?

320. How much lime can be made from 5 tons of limestone containing 95% calcium carbonate?

321. What volume of carbon dioxide will be available in the above reaction?

322. What volume of carbon dioxide must be absorbed by 14 grams of quicklime before it is completely air-slaked?

323. What will be the final weight of this air-slaked lime?

324. What volume of carbon dioxide can be obtained from the heating of 1 kg. of marble containing 95% of calcium carbonate?

325. How many gallons of water, each weighing 8.35 lb., will be needed to make 222 lb. of slaked lime from quicklime?

30. CALCIUM SALTS

Com. Prep.

$6H_2O + Ca_3(PO_4)_2 + 2H_2SO_4 \longrightarrow 2CaSO_4 \cdot 2H_2O$
$+ Ca(H_2PO_4)_2 \cdot 2H_2O$ (Superphosphate of lime)

$CaSO_4 + 2H_2O \longrightarrow CaSO_4 \cdot 2\ H_2O$ (Gypsum)

$2CaSO_4 \cdot 2H_2O \longrightarrow 3H_2O + (CaSO_4)_2 \cdot H_2O$ (Plaster of Paris)

$CaCN_2 + C + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCN$ (Preparation of sodium cyanide)

$Ca(OH)_2 + Cl_2 \longrightarrow H_2O + CaCl \cdot OCl$ (Bleaching powder)

$CaCl \cdot OCl + 2HCl \longrightarrow CaCl_2 + H_2O + \uparrow 2Cl$ (Decomposition of bleaching powder)

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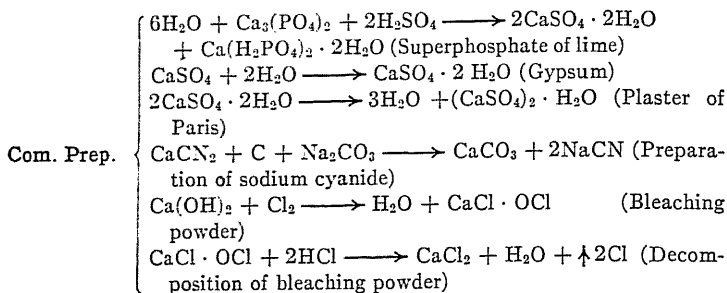
326. What is the percentage of chlorine in bleaching powder?

327. Determine the percentage composition of crystallized superphosphate of lime.

328. What volume of chlorine will react with 33.3 grams of dry calcium hydroxide in the preparation of bleaching powder?

329. What weight of plaster of Paris can be made from 8.6 tons of gypsum?

330. What volume of chlorine will be liberated when hydrochloric acid completely reacts with 76.2 grams of bleaching powder?

331. What weight of sodium cyanide can be prepared from 400 lb. of calcium cyanamid?

332. How much superphosphate of lime can be prepared from 100 tons of bones containing 70% calcium phosphate?

333. A manufacturer must turn out 50 tons of bleaching powder. What weight of slaked lime and what volume of chlorine will he need?

334. What volume of steam will be given off when 8.6 grams of gypsum are completely burned?

335. How much superphosphate of lime, containing 2 molecules of water of crystallization, can be prepared from 50 tons of an ore containing 75% pure calcium phosphate?

336. A tube containing calcium chloride weighs 200 grams. 80 liters of air is sent through the tube, which is again weighed and found to be 201.7 grams. Calculate from these data the percentage of moisture in the air.

31. MAGNESIUM

Com. Prep. $MgCl_2 \longrightarrow Mg + Cl_2$ (Electrolysis of fused $MgCl_2$)

Chem. Prop.
$\begin{cases} 2Mg + O_2 \longrightarrow 2MgO \text{ (Burns in air with a bright white} \\ \quad \text{light)} \\ 3Mg + N_2 \longrightarrow Mg_3N_2 \text{ (Unites to a small extent with} \\ \quad \text{nitrogen of the air)} \\ Mg + H_2SO_4 + 7H_2O \longrightarrow MgSO_4 \cdot 7H_2O + \uparrow H_2 \\ \quad \text{(Formation of Epsom salt)} \\ Mg + 2H_2O \longrightarrow Mg(OH)_2 + \uparrow H_2 \text{ (Reacts with boiling} \\ \quad \text{water to liberate } H_2) \end{cases}$

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337. Find the percentage of magnesium in: talc, $H_2Mg_3(SiO_3)_4$; serpentine, $(MgFe)_3Si_2O_7 \cdot 2H_2O$; and carnallite, $MgCl_2 \cdot KCl \cdot 6H_2O$.

338. Determine the percentage of water of crystallization in Epsom salt, $MgSO_4 \cdot 7H_2O$.

339. Find the weight of magnesium obtainable from one ton each of dolomite ($CaCO_3 \cdot MgCO_3$) and magnesite ($MgCO_3$).

340. How much Epsom salt can be obtained from one pound of pure magnesium?

341. What volume of nitrogen will be required to react completely with magnesium and form 10 grams of magnesium nitride?

342. What volume of air will be required to burn completely 2 grams of magnesium to magnesium oxide? Assume air to contain 21% oxygen.

343. A certain weight of magnesium was placed in boiling water and 50 cc. of hydrogen gas measured at 17° and 760 mm. were liberated. What weight of water was decomposed?

344. A compound contained 13% sulfur, 71.5% oxygen, 9.8% magnesium, and 5.7% hydrogen. What is the simplest formula of this compound?

345. What volume of H_2SO_4 containing 70% H_2SO_4 (Sp. Gr., 1.61) will be needed to react completely with 4 grams of magnesium?

346. Magnesium ribbon reacted with 20 cc. of steam. What weight of hydrogen was formed?

347. What volume of chlorine, measured at 20° and 760 mm., can be obtained by the electrolysis of 190 lb. of fused $MgCl_2$?
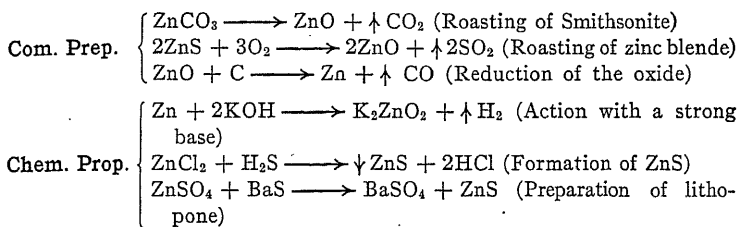
32. MERCURY

Com. Prep. $HgS + O_2 \longrightarrow Hg + SO_2$ (Extraction of Hg from cinnabar)

Chem. Prop.
$$\begin{cases} Cu + Hg(NO_3)_2 \longrightarrow \downarrow Hg + Cu(NO_3)_2 \text{ (Replacement of} \\ \quad \text{Hg by copper)} \\ HgCl_2 + Hg \longrightarrow 2HgCl \text{ (Reduction of } HgCl_2 \text{ with Hg)} \\ 2HgCl_2 + SnCl_2 \longrightarrow SnCl_4 + 2HgCl \text{ (Action of } SnCl_2 \text{ on} \\ \quad \text{bichloride of mercury)} \\ 2HgCl + SnCl_2 \longrightarrow SnCl_4 + \downarrow 2Hg \text{ (Reduction of HgCl} \\ \quad \text{by stannous chloride)} \end{cases}$$

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348. The specific gravity of mercury vapor is 6.91. Determine its molecular weight, the weight of one liter of its vapor, and its vapor density.

349. Calculate the simplest formula of a mercury compound containing 92.6% mercury and the remainder oxygen.

350. What weight of mercury must be added to 10.84 grams of bichloride of mercury to change it completely into mercurous chloride (calomel)?

351. How much mercury fulminate, $Hg(OCN)_2$, can be prepared from 100 lb. of mercury?

352. One ton of an ore containing 85% of HgS was roasted. What weight of mercury was obtained?

353. What volume of sulfur dioxide gas was liberated in the above reaction?

354. A strip of copper weighing 2 grams is placed in a solution containing an equal weight of mercuric nitrate. What weight of mercury was deposited?

355. Stannous chloride was added to a solution containing 4.42 grams of bichloride of mercury. One gram of calomel (HgCl) was precipitated. What weight of stannous chloride was used?

356. Calculate the volume of oxygen obtained by heating 36 grams of mercuric oxide.

357. What weight of mercury and what volume of sulfur dioxide can be prepared from 100 lb. of cinnabar, containing 92% HgS?

33. ZINC

Com. Prep. $\begin{cases} ZnCO_3 \longrightarrow ZnO + \uparrow CO_2 \text{ (Roasting of Smithsonite)} \\ 2ZnS + 3O_2 \longrightarrow 2ZnO + \uparrow 2SO_2 \text{ (Roasting of zinc blende)} \\ ZnO + C \longrightarrow Zn + \uparrow CO \text{ (Reduction of the oxide)} \end{cases}$

Chem. Prop. $\begin{cases} Zn + 2KOH \longrightarrow K_2ZnO_2 + \uparrow H_2 \text{ (Action with a strong} \\ \qquad \text{base)} \\ ZnCl_2 + H_2S \longrightarrow \downarrow ZnS + 2HCl \text{ (Formation of ZnS)} \\ ZnSO_4 + BaS \longrightarrow BaSO_4 + ZnS \text{ (Preparation of litho-} \\ \qquad \text{pone)} \end{cases}$

358. Calculate the percentage of zinc in the following compounds: zinc carbonate, zinc sulfate, zinc oxide, and zinc sulfide.

359. A compound contains 43.9% water, 22.7% zinc, 11.1% sulfur, and 22.3% oxygen. What is the simplest formula of this compound?

360. Find the formula of a zinc sulfide which contained 67% zinc and 33% oxygen.

361. The vapor density of zinc vapor was found to be equal to 32.5. Determine the weight of a liter of this vapor, and its molecular weight.

362. What weight of carbon is needed to reduce 243 lb. of zinc oxide, the carbon being oxidized only to carbon monoxide?

363. How much zinc would be necessary to produce 10 grams of crystallized zinc sulfate $(ZnSO_4 \cdot 7H_2O)$?

364. What weight of carbon dioxide would be given off on heating 1 kg. of zinc carbonate?

365. What volume of hydrogen sulfide would be needed to precipitate 19.4 grams of zinc sulfide from a sufficient amount of zinc chloride solution?

366. What volume of air would be used in the roasting of 48.5 grams of zinc sulfide?

367. What weights of $ZnSO_4$ and BaS will be needed to make 33 tons of lithopone?
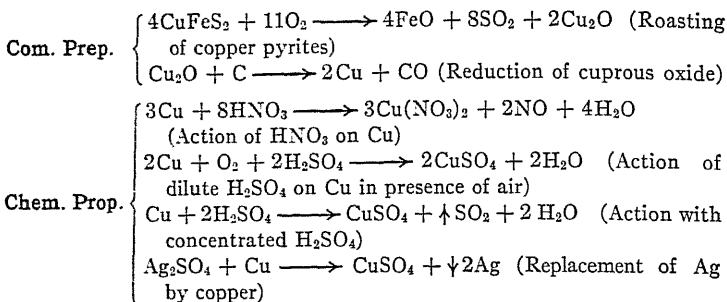
34. MANUFACTURE OF IRON AND STEEL

Com. Prep.

$Fe_2O_3 + 3C \longrightarrow 2Fe + \uparrow 3CO$ (Reduction of hematite with coke)

$Fe_2O_3 + 3CO \longrightarrow 2Fe + \uparrow 3CO_2$ (Reduction of hematite with CO)

$CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + \uparrow CO_2$ (Production of slag)

$2CaO + 2S + 3O_2 \longrightarrow 2CaSO_4$ (Removal of S)

$6CaO + 4P + 5O_2 \longrightarrow 2Ca_3(PO_4)_2$ (Removal of P)

$3Fe + C \longrightarrow Fe_3C$ (Formation of iron carbide)

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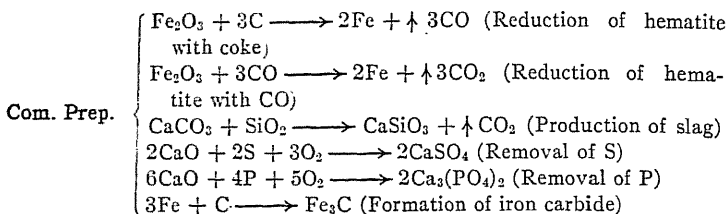
368. Calculate the percentage of iron in each of these ores: hematite, Fe_2O_3; magnetite, Fe_3O_4; siderite, $FeCO_3$; and limonite, $Fe_2O_3 \cdot 3H_2O$.

369. What volume of air would be required to oxidize all of the carbon present in 5 tons of cast iron, containing 3.5% carbon?

370. It is required to produce 100 tons of steel containing 0.5% of carbon from pig iron containing 4.5% carbon. What volume of air will be needed?

371. 100 tons of iron ore containing 5% calcium carbonate is to be smelted. What weight of sand must be added to remove completely all this calcium as slag?

372. How many tons of coke containing 98% carbon are needed to reduce 500 tons of hematite containing 88% Fe_2O_3?

373. What volume of carbon monoxide is necessary to reduce 3.2 grams of Fe_2O_3?

374. An ore of iron showed on analysis 7% sand and 10% limestone. What weight of flux would have to be added in the smelting of 100 tons of this ore?

375. It is required to make 100 tons of cast iron containing 95% iron. What weight of an iron ore containing 90% siderite, $FeCO_3$, would be required?

376. What volume of carbon monoxide is necessary to reduce 2.976 grams of hematite containing 93% Fe_2O_3?

377. 9.5 grams of iron yielded 13.6 grams of Fe_2O_3. Calculate the atomic weight of iron.

35. IRON SALTS

Com. Prep.
$$\begin{cases} 4KCN + Fe(CN)_2 \longrightarrow K_4Fe(CN)_6 \text{ (Preparation of potassium ferrocyanide)} \\ 2K_4Fe(CN)_6 + Cl_2 \longrightarrow 2KCl + 2K_3Fe(CN)_6 \text{ (Preparation of potassium ferricyanide)} \end{cases}$$

Lab. Prep. $FeCl_3 + 3NH_4OH \longrightarrow 3NH_4Cl + \downarrow Fe(OH)_3$ (Precipitation of ferric hydroxide)

Chem. Prop.
$$\begin{cases} 3Fe + 4H_2O \longrightarrow Fe_3O_4 + \uparrow 4H_2 \text{ (Action of hot iron on steam)} \\ 2FeCl_2 + Cl_2 \longrightarrow 2FeCl_3 \text{ (Oxidation of ferrous chloride)} \\ 2FeCl_3 + H_2 \longrightarrow 2HCl + 2FeCl_2 \text{ (Reduction of ferric chloride)} \\ 4FeCl_3 + 3K_4Fe(CN)_6 \longrightarrow 12KCl + \downarrow Fe_4(Fe(CN)_6)_3 \\ \text{(Prussian blue — test for a ferric salt)} \\ 3FeCl_2 + 2K_3Fe(CN)_6 \longrightarrow 6KCl + \downarrow Fe_3(Fe(CN)_6)_2 \\ \text{(Turnbull's blue — test for a ferrous salt)} \end{cases}$$

378. Determine the percentage composition of Prussian blue.

379. What is the percentage composition of green vitriol $(FeSO_4 \cdot 7H_2O)$?

380. What is the simplest formula of a compound containing 15.2% Fe, 42.4% K, 19.6% C, and 22.8% N?

381. Let us take for the formula of limonite $(Fe_2O_3)_2 \cdot 3H_2O$. What weight of iron could 10 tons of this ore furnish?

382. What weight of ferric chloride could be theoretically reduced by 5 liters of hydrogen gas?

383. What weight of Prussian blue could be formed from 73.6 lb. of potassium ferrocyanide?

384. How much ferrous chloride would be needed to prepare 2.71 grams of Turnbull's blue?

385. What weight of $FeSO_4$ would result by the action of 100 grams of pure iron on sulfuric acid? What volume of hydrogen would be evolved?

386. What volume of chlorine would have to be passed over hot iron to form 100 grams of ferric chloride, provided all the chlorine reacted with the iron?

387. What weight of ferric salt could be obtained by the oxidation of 381 grams of ferrous chloride with free chlorine?

388. What volume of chlorine will be required to change 18.4 grams of potassium ferrocyanide to the ferricyanide?

36. COPPER

Com. Prep. $\begin{cases} 4CuFeS_2 + 11O_2 \longrightarrow 4FeO + 8SO_2 + 2Cu_2O \text{ (Roasting of copper pyrites)} \\ Cu_2O + C \longrightarrow 2Cu + CO \text{ (Reduction of cuprous oxide)} \end{cases}$

Chem. Prop. $\begin{cases} 3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O \\ \text{(Action of } HNO_3 \text{ on Cu)} \\ 2Cu + O_2 + 2H_2SO_4 \longrightarrow 2CuSO_4 + 2H_2O \text{ (Action of dilute } H_2SO_4 \text{ on Cu in presence of air)} \\ Cu + 2H_2SO_4 \longrightarrow CuSO_4 + \uparrow SO_2 + 2H_2O \text{ (Action with concentrated } H_2SO_4) \\ Ag_2SO_4 + Cu \longrightarrow CuSO_4 + \downarrow 2Ag \text{ (Replacement of Ag by copper)} \end{cases}$

389. Determine the percentage composition of the following copper ores: copper pyrites, $CuFeS_2$; malachite, $Cu_2(OH)_2CO_3$; azurite, $Cu_3(OH)_2(CO_3)_2$; and cuprite, Cu_2O.

390. A compound was found to contain 53.1% silver, 31.1% copper, and 15.8% sulfur. Determine the simplest formula of this compound.

391. How many grams of copper must be heated to form 32 grams of copper oxide?

392. What weight of Cu_2O could be reduced by 100 lb. of carbon, assuming all the carbon is oxidized to carbon dioxide?

393. What weight of copper will a ton of ore, containing 80% malachite, yield?

394. What weight of silver will a gram of copper replace in a solution containing 6 grams of silver sulfate?

395. A strip of copper was placed in a silver sulfate solution. After a while it was taken out and found to have lost 2.3 grams. What weight of copper sulfate was formed?

396. What weight of silver will be precipitated by copper from a solution containing 3.12 grams of silver sulfate?

397. What volume of nitric oxide is liberated when 8 grams of copper is completely dissolved by nitric acid? What weight of copper nitrate is formed?

398. A copper coin liberated 20 grams of SO_2 from H_2SO_4. What is the weight of the coin?

37. SILVER, GOLD, AND PLATINUM

Chem. Prop.
$\Big\{$

$3Ag + 4HNO_3 \longrightarrow 3AgNO_3 + 2H_2O + NO$ (Action of HNO_3 on silver)

$2Ag + 2H_2SO_4 \longrightarrow Ag_2SO_4 + 2H_2O + SO_2$ (Action with conc. H_2SO_4)

$Ag_2SO_4 + Cu \longrightarrow CuSO_4 + \downarrow 2Ag$ (Replacement of Ag by copper)

$AgNO_3 + KCl \longrightarrow \downarrow AgCl + KNO_3$ (Test for a chloride)

$KCN + AgCN \longrightarrow KAg(CN)_2$ (Formation of a complex silver salt)

$4AgOH + HCHO \longrightarrow 3H_2O + CO_2 + \downarrow 4Ag$ (Reduction of Ag salt by formaldehyde)

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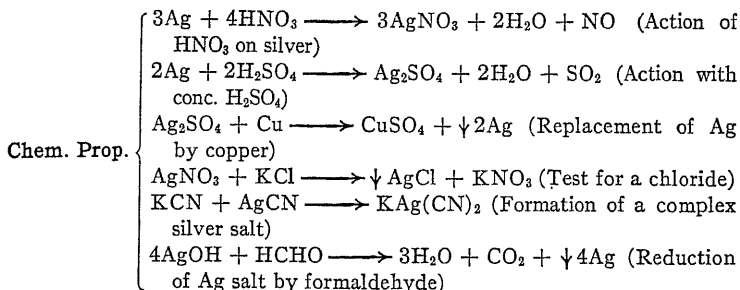
399. Determine the percentage of silver present in each of these two silver ores: pyrargyrite, Ag_3SbS_3, and prousite, Ag_3AsS_3.

400. A compound contains 16% potassium, 40.4% platinum, and 43.6% chlorine. What is the simplest formula of this compound?

401. What weight of $PtCl_4$ can be obtained by dissolving 19.5 grams of platinum in aqua regia?

402. A silver dollar weighs 26.5 grams. It contains 90% silver. What weight of silver nitrate could be prepared from this coin?

403. Calculate the weights of the sulfates of silver and copper which could be made from a dime weighing 2.48 grams and containing 10% copper.

404. What weight of pure copper would be needed to replace completely all the silver in a liter of silver sulfate containing 10 grams of the salt in solution?

405. On dissolving a batch of platinum ore in aqua regia, 41 grams of chlorplatinic acid, H_2PtCl_6, were obtained. What weight of platinum was present in the ore?

406. How many grams of silver can be obtained from 85 grams of silver nitrate by simple replacement?

407. One gram of silver is dissolved in nitric acid and to it are added 0.2 gram of sodium chloride. How many grams of silver salt remain in solution?

408. What volume, in cubic centimeters, of nitric oxide is evolved when 54 grams of silver are completely dissolved in nitric acid? What is the weight of this gas?
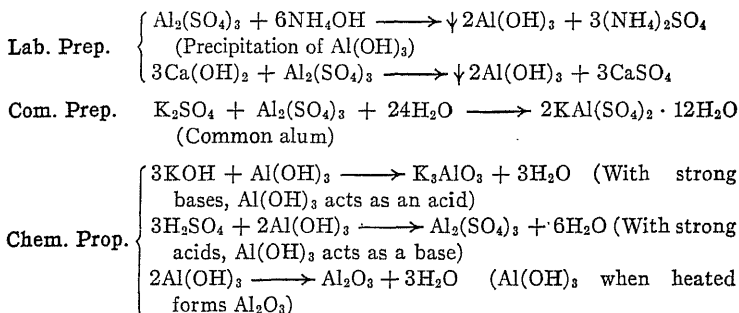
38. ALUMINUM

Com. Prep. $2Al_2O_3 \longrightarrow 4Al + 3O_2$ (Electrolysis of bauxite)

Chem. Prop.
$\begin{cases}
2Al + 6HCl \longrightarrow 2AlCl_3 + \uparrow 3H_2 \\
2Al + 6H_2SO_4 \longrightarrow Al_2(SO_4)_3 + 3SO_2 + 6H_2O \quad \text{(Conc.} \\
\quad H_2SO_4 \text{ dissolves aluminum)} \\
2Al + 6NaOH \longrightarrow 2Na_3AlO_3 + \uparrow 3H_2 \text{ (Action of alumi-} \\
\quad \text{num with a boiling solution of NaOH)} \\
Fe_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Fe \text{ (Thermit process)} \\
Cr_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Cr \text{ (Preparation of Cr by} \\
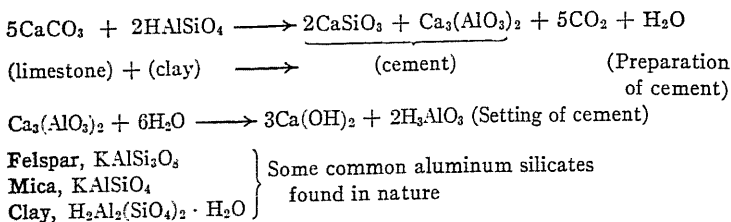\quad \text{means of Al)}
\end{cases}$

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409. How much aluminum is available in 204 tons of bauxite, containing 85% Al_2O_3?

410. A compound contains 13% aluminum, 54.2% fluorine, and 32.8% sodium. What is its simplest formula?

411. Magnalium is an alloy containing 95% aluminum and 5% magnesium. What weight of bauxite would be required to prepare 1 kg. of this alloy?

412. What weight of carbon electrode would have to be replaced after 51 tons of aluminum oxide have been decomposed in the Hall electrolytic process?

413. It is necessary to produce 1 ton of molten iron for a thermit welding operation. How much aluminum will be required?

414. What weight of chromium metal can be produced by the thermit process from 76 kg. of a chromium ore containing 50% of chromium oxide?

415. 10 grams of anhydrous aluminum chloride were prepared by the action of hydrochloric acid on aluminum. What weight of aluminum was dissolved?

416. 4.77 grams of crystallized aluminum sulfate lost 2.3 grams of water after being heated. Find its formula.

417. 0.37 gram of aluminum liberated 0.04 gram of hydrogen from a strong solution of sodium hydroxide. Knowing the valency of aluminum to be 3, find the atomic weight of aluminum.

418. What weights of materials must be used in the thermit process to form 14 lb. of molten iron?
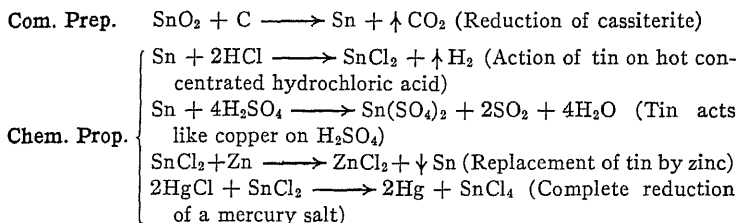
39. ALUMINUM HYDROXIDE AND ALUMS

Lab. Prep.
$$\begin{cases} Al_2(SO_4)_3 + 6NH_4OH \longrightarrow \downarrow 2Al(OH)_3 + 3(NH_4)_2SO_4 \\ \text{(Precipitation of Al(OH)}_3) \\ 3Ca(OH)_2 + Al_2(SO_4)_3 \longrightarrow \downarrow 2Al(OH)_3 + 3CaSO_4 \end{cases}$$

Com. Prep. $K_2SO_4 + Al_2(SO_4)_3 + 24H_2O \longrightarrow 2KAl(SO_4)_2 \cdot 12H_2O$
(Common alum)

Chem. Prop.
$$\begin{cases} 3KOH + Al(OH)_3 \longrightarrow K_3AlO_3 + 3H_2O \quad \text{(With strong bases, Al(OH)}_3 \text{ acts as an acid)} \\ 3H_2SO_4 + 2Al(OH)_3 \longrightarrow Al_2(SO_4)_3 + 6H_2O \text{ (With strong acids, Al(OH)}_3 \text{ acts as a base)} \\ 2Al(OH)_3 \longrightarrow Al_2O_3 + 3H_2O \quad \text{(Al(OH)}_3 \text{ when heated forms Al}_2O_3) \end{cases}$$

419. Determine the percentage composition of chrom alum $(KCrSO_4)_2 \cdot 12H_2O$, and ammonium alum, $NH_4Al(SO_4)_2 \cdot 12H_2O$.

420. What weight of aluminum hydroxide can be precipitated by 17.1 lb. of aluminum sulfate?

421. 117 grams of aluminum hydroxide is to be prepared from aluminum sulfate. What weight of ammonia (NH_3) will be required?

422. How much aluminum oxide can be obtained from 39 grams of aluminum hydroxide?

423. It is required to prepare 2.34 grams of dry aluminum hydroxide. What weight of aluminum sulfate will be needed?

424. What weight of commercial NaOH (containing 10% water) will be required to neutralize 195 grams of aluminum hydroxide?

425. What weights of potassium and chromium sulfates will be needed to prepare 99.8 grams of chrome alum, $KCr(SO_4)_2 \cdot 12H_2O$?

426. What weight of crystallized ferric ammonium alum can be made from 40 grams of ferric sulfate and 15 grams of ammonium sulfate?

427. How many pounds of water are found chemically combined in 237 lb. of common alum?

428. 19 grams of aluminum hydroxide lost, on heating, 6.56 grams, leaving Al_2O_3. What is the molecular weight of aluminum hydroxide?

429. 0.918 gram of $Al(OH)_3$ is obtained from an aluminum alloy weighing 2.5 grams. What percentage of aluminum is present in the alloy?

40. ALUMINUM SILICATES AND CEMENT

$$5CaCO_3 + 2HAlSiO_4 \longrightarrow \underbrace{2CaSiO_3 + Ca_3(AlO_3)_2} + 5CO_2 + H_2O$$

(limestone) + (clay) $\longrightarrow$ (cement) (Preparation of cement)

$$Ca_3(AlO_3)_2 + 6H_2O \longrightarrow 3Ca(OH)_2 + 2H_3AlO_3 \text{ (Setting of cement)}$$

Felspar, $KAlSi_3O_8$ ⎫ Some common aluminum silicates
Mica, $KAlSiO_4$ ⎬ found in nature
Clay, $H_2Al_2(SiO_4)_2 \cdot H_2O$ ⎭

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430. Determine the percentage composition of the aluminum silicates given above.

431. Determine the percentage composition of mica by elements and oxides.

432. What weight of water will be needed in the setting of 60 lb. of cement?

433. Assuming that the first equation above represents the chemical reaction for the making of cement, what weights of limestone and clay should be heated together to obtain 100 tons of cement?

434. A compound contains 24.7% potassium, 17.1% aluminum, 17.7% silicon, and 40.5% oxygen. Determine its simplest formula.

435. What volume of carbon dioxide is liberated in the making of 5.92 kg. of cement?

436. 120 tons of a clay containing 80% $HAlSiO_4$ are available. What weight of cement can be made from this clay?

437. A compound contains 14% potassium, 10% aluminum, 30% silicon, and 46% oxygen. Determine the simplest formula of this substance.

438. What weight of aluminum is contained in a sample of garnet containing 98% of $Ca_3Al_2(SiO_4)_3$ and weighing 7.5 g.?

439. In the complete setting of a sample of cement, 3.7 grams of $Ca(OH)_2$ were produced. What weight of limestone was used in the making of this cement?

440. What volume of carbon dioxide measured at 17° and 760 mm. is liberated in the making of 1184 tons of cement?
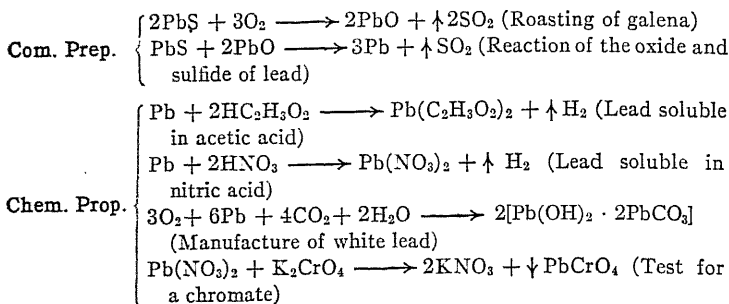
41. TIN AND THE ELECTROCHEMICAL SERIES

Com. Prep. $SnO_2 + C \longrightarrow Sn + \uparrow CO_2$ (Reduction of cassiterite)

Chem. Prop. $\begin{cases} Sn + 2HCl \longrightarrow SnCl_2 + \uparrow H_2 \text{ (Action of tin on hot concentrated hydrochloric acid)} \\ Sn + 4H_2SO_4 \longrightarrow Sn(SO_4)_2 + 2SO_2 + 4H_2O \text{ (Tin acts like copper on } H_2SO_4) \\ SnCl_2 + Zn \longrightarrow ZnCl_2 + \downarrow Sn \text{ (Replacement of tin by zinc)} \\ 2HgCl + SnCl_2 \longrightarrow 2Hg + SnCl_4 \text{ (Complete reduction of a mercury salt)} \end{cases}$

Electrochemical Series: Na—Ca—Mg—Al—Zn—Fe—Ni—Sn—Pb—
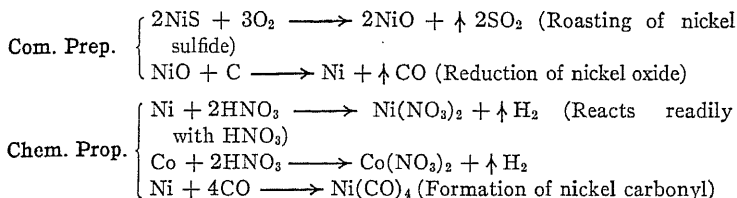H—Cu—As—Hg—Ag—Pt—Au

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441. Determine the percentage composition of the two chlorides of tin.

442. A compound contains 52.6% tin, 31.4% chlorine, 1.8% hydrogen, and 14.2% oxygen. What is the simplest formula of this compound?

443. How much carbon would be needed for the reduction of 151 kg. of tin oxide?

444. 50 grams of free mercury were obtained by the reduction of a solution of mercuric chloride with a stannous chloride solution. What weight of bichloride of mercury was reduced?

445. What weight of carbon will be required for the reduction of 302 lb. of cassiterite, containing 75% SnO_2?

446. What weight of ferric chloride could be reduced to the ferrous condition with the aid of 9.5 grams of stannous chloride?

447. In the reduction of a sample of SnO_2, 250 cc. of carbon dioxide, measured under standard conditions, were obtained. What was the weight of oxide reduced?

448. What weight of zinc would be needed to replace completely all the tin in 10 liters of a solution containing 38 grams of stannous chloride per liter?

449. 10 grams of tin were heated in concentrated HCl, and as a result 55 cc. of hydrogen, measured at 17° C. and 760 mm., were given off. What weight of the tin actually dissolved in the acid?

450. What weight of tin will be needed to replace completely all the copper present in a solution containing 25 grams of crystallized copper sulfate?

42. LEAD

Com. Prep. $\begin{cases} 2PbS + 3O_2 \longrightarrow 2PbO + \uparrow 2SO_2 \text{ (Roasting of galena)} \\ PbS + 2PbO \longrightarrow 3Pb + \uparrow SO_2 \text{ (Reaction of the oxide and} \\ \quad \text{sulfide of lead)} \end{cases}$

Chem. Prop. $\begin{cases} Pb + 2HC_2H_3O_2 \longrightarrow Pb(C_2H_3O_2)_2 + \uparrow H_2 \text{ (Lead soluble} \\ \quad \text{in acetic acid)} \\ Pb + 2HNO_3 \longrightarrow Pb(NO_3)_2 + \uparrow H_2 \text{ (Lead soluble in} \\ \quad \text{nitric acid)} \\ 3O_2 + 6Pb + 4CO_2 + 2H_2O \longrightarrow 2[Pb(OH)_2 \cdot 2PbCO_3] \\ \quad \text{(Manufacture of white lead)} \\ Pb(NO_3)_2 + K_2CrO_4 \longrightarrow 2KNO_3 + \downarrow PbCrO_4 \text{ (Test for} \\ \quad \text{a chromate)} \end{cases}$
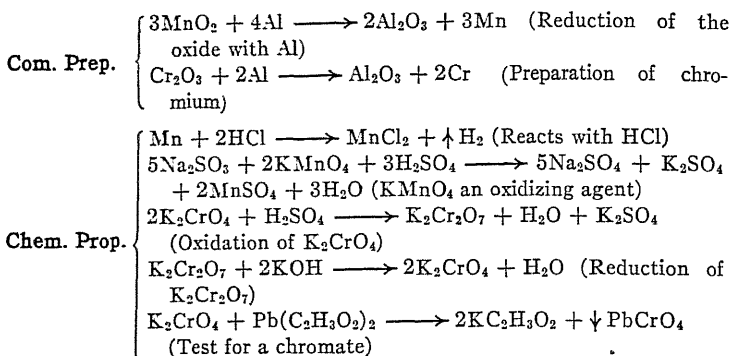
451. Determine the percentage composition of white lead as made by the Dutch process, if its composition is expressed by the formula written above.

452. A compound was found to contain 90.65% lead and 9.35% oxygen. What is its simplest formula?

453. Find the simplest formula of a compound which on analysis gave the following composition: 62.45% lead, 8.7% nitrogen, and 28.85% oxygen.

454. A sample of galena from Colorado showed on analysis the presence of 95% PbS. 956 tons of this ore were roasted. What weight of lead was obtained?

455. What weight of lead would have to be treated to obtain one ton of white lead?

456. At the prices of 10¢ per pound for lead and 6¢ per pound for glacial acetic acid, what would be the cost of the chemicals used in preparing one ton of pure lead acetate?

457. What weight of lead will be found in a volume of tetraethyl lead, $Pb(C_2H_5)_4$, weighing 9.69 grams?

458. Potassium chromate is added to a solution containing lead nitrate, and 6.46 grams of lead chromate are precipitated. What weight of lead nitrate was present in solution?

459. In converting 111.5 lb. of PbO into Pb_3O_4, what volume of oxygen is used?

460. 8.78 grams of PbO yielded 8.15 grams of lead. What is the atomic weight of lead?

43. NICKEL AND COBALT

Com. Prep. $\begin{cases} 2NiS + 3O_2 \longrightarrow 2NiO + \uparrow 2SO_2 \text{ (Roasting of nickel} \\ \quad \text{sulfide)} \\ NiO + C \longrightarrow Ni + \uparrow CO \text{ (Reduction of nickel oxide)} \end{cases}$

Chem. Prop. $\begin{cases} Ni + 2HNO_3 \longrightarrow Ni(NO_3)_2 + \uparrow H_2 \text{ (Reacts readily} \\ \quad \text{with } HNO_3) \\ Co + 2HNO_3 \longrightarrow Co(NO_3)_2 + \uparrow H_2 \\ Ni + 4CO \longrightarrow Ni(CO)_4 \text{ (Formation of nickel carbonyl)} \end{cases}$

461. Determine the amount of Ni present in the nickel ammonium sulfate crystals, $NiSO_4(NH_4)_2SO_4 \cdot 6H_2O$, used in the nickel plating bath.

462. Determine the percentage composition of cobaltite (CoAsS), crystallized cobalt nitrate, $Co(NO_3)_2 \cdot 6H_2O$, and nickel glance (NiAsS).

463. Cobalt is obtained chiefly from cobalt glance, whose formula may be represented as $CoAs_2 \cdot CoS_2$. Determine the weight of cobalt available in 1 ton of this ore containing 50% cobalt glance.

464. How much of a 5% solution by weight of cobalt nitrate can be obtained by dissolving 5.9 grams of cobalt in nitric acid?

465. 50 cc. of carbon monoxide completely react with metallic nickel. What weight of nickel carbonyl is produced?

466. 27.3 lb. of nickel sulfide (NiS) are roasted. What weight of nickel oxide and what volume of sulfur dioxide are produced?

467. Which will produce a greater volume of hydrogen: 6 grams of nickel or 5.5 grams of zinc reacting with nitric acid?

468. A manufacturer requires 1 lb. of pure nickel as a catalyst in the hydrogenation of an oil. What weight of pure $NiSO_4$ must be treated to obtain this weight of catalyst?

469. What volume of carbon monoxide will be liberated by the decomposition of 5 liters of the vapor of nickel carbonyl?

470. What weight of nickel will be left in the above operation?

471. 12.5 grams of nickel oxide were reduced in a stream of hydrogen and lost 2.67 grams in weight. The specific heat of nickel is 0.095. Calculate the atomic weight of this element.

44. MANGANESE AND CHROMIUM

Com. Prep.
$$3MnO_2 + 4Al \longrightarrow 2Al_2O_3 + 3Mn \text{ (Reduction of the oxide with Al)}$$
$$Cr_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Cr \text{ (Preparation of chromium)}$$

Chem. Prop.
$$Mn + 2HCl \longrightarrow MnCl_2 + \uparrow H_2 \text{ (Reacts with HCl)}$$
$$5Na_2SO_3 + 2KMnO_4 + 3H_2SO_4 \longrightarrow 5Na_2SO_4 + K_2SO_4 + 2MnSO_4 + 3H_2O \text{ (KMnO}_4 \text{ an oxidizing agent)}$$
$$2K_2CrO_4 + H_2SO_4 \longrightarrow K_2Cr_2O_7 + H_2O + K_2SO_4 \text{ (Oxidation of K}_2CrO_4)$$
$$K_2Cr_2O_7 + 2KOH \longrightarrow 2K_2CrO_4 + H_2O \text{ (Reduction of K}_2Cr_2O_7)$$
$$K_2CrO_4 + Pb(C_2H_3O_2)_2 \longrightarrow 2KC_2H_3O_2 + \downarrow PbCrO_4 \text{ (Test for a chromate)}$$

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472. Determine the percentage composition of chromite, $Fe(CrO_2)_2$, and hausmannite, Mn_3O_4.

473. What is the factor of K_2O in potassium permanganate?

474. In 100 parts of a compound are found 63.2 parts of manganese and 36.8 parts of oxygen. What is its simplest formula?

475. What weight of chrome yellow, $PbCrO_4$, is formed when a solution containing 9.7 grams of potassium chromate is precipitated with lead acetate?

476. What weight of aluminum powder must be used in the thermit process to obtain all the chromium from 100 grams of Cr_2O_3?

477. A solution containing 4.5 grams of sodium sulfite completely decolorized a solution of potassium permanganate. What weight of $KMnO_4$ was present in the solution?

478. A pyrolusite ore was found on analysis to contain 85% MnO_2. What weight of manganese could be obtained by the thermit process from 10 tons of this ore?

479. What weight of sodium sulfite can be oxidized by 79 grams of potassium permanganate?

480. What volume of hydrogen will be evolved when 100 cc. of HCl containing 20% HCl (Sp. Gr., 1.1) completely reacts with manganese?

481. What weight of chrome yellow will be precipitated by lead acetate added, in sufficient quantities, to a solution containing 9.7 lb. of potassium chromate?

45. DISTILLATION PRODUCTS OF COAL, WOOD, AND PETROLEUM

DESTRUCTIVE DISTILLATION		FRACTIONAL DISTILLATION
Coal (2000 lb.)	Wood	Petroleum
Illuminating gas 10,000 cu. ft. Coke . . . . . 1325 lb. Ammonia . . . . . 5 lb. Hydrogen sulfide . (variable) Coal tar $\begin{cases} \text{benzene} \\ \text{phenol} \\ \text{pitch} \end{cases}$. 12 gal.	Gas fuel Charcoal Wood tar Pyroligneous $\begin{cases} \text{acetic acid} \\ \text{acetone} \\ \text{wood alcohol} \end{cases}$ acid	Gasoline . . C_6H_{14} and C_7H_{16} Naphtha . . C_7H_{16} and C_8H_{18} Benzine . . C_8H_{18} and C_9H_{20} Kerosene . . $C_{10}H_{22}$ and $C_{16}H_{34}$ Lubricating oils Paraffin . . $C_{22}H_{46}$ and $C_{28}H_{58}$ Vaseline . . $C_{22}H_{46}$ and $C_{23}H_{48}$

482. Assuming the composition of vaseline to be $C_{22}H_{46}$, determine its percentage composition.

483. A ton of coal yielded 5 lb. of ammonia gas. What is the percentage of nitrogen in the coal?

484. Determine the percentage composition of petroleum ether, assuming that it consists of equal parts of C_5H_{12} and C_6H_{14}.

485. The vapor density of one of the hydrocarbons found in gasoline is 49.9. It contains 83.9% carbon and 16.1% hydrogen. Determine its true formula.

486. What weight of oxygen would be used in completely burning 10 grams of petroleum ether, assuming it to be composed of equal parts of C_5H_{12} and C_6H_{14}?

487. What volume of air would be required for the complete combustion of 1 lb. of kerosene, assuming the formula of kerosene to be $C_{10}H_{22}$?

488. A coal, on analysis, showed the presence of 0.75% nitrogen. What volume of ammonia could be obtained from 100 tons of this coal, assuming all its nitrogen to be changed to ammonia during the destructive distillation?

489. An analysis of coal gas showed the presence of 50% hydrogen, 35% methane, and 5% carbon monoxide, by volume. What volume of oxygen will be needed to burn completely 1000 cu. ft. of this gas?

490. What volume of carbon dioxide would be produced in the above reaction?

491. A ton of coal gave 10,000 cu. ft. of illuminating gas containing 30.5% methane and 5% carbon monoxide by volume. What weight of carbon dioxide would be produced by the complete combustion of this volume of gas?

46. HYDROCARBONS

Methane Series	Ethylene Series	Acetylene Series
CH_4 methane C_2H_6 ethane C_3H_8 propane $CHCl_3$ chloroform ⎫ halogen CHI_3 iodoform ⎬ substitution CCl_4 carbona ⎭ products	C_2H_4 ethylene C_3H_6 propylene	C_2H_2 acetylene
		Benzene Series
		C_6H_6 benzene $C_6H_5CH_3$ toluene

$2C_6H_6 + 15O_2 \longrightarrow 12CO_2 + 6H_2O$ (CO_2 and H_2O always formed by the complete combustion of a hydrocarbon)

$CS_2 + 3Cl_2 \longrightarrow S_2Cl_2 + CCl_4$ (Preparation of carbon tetrachloride)

$CH_3C_6H_5 + 3HNO_3 \longrightarrow 3H_2O + CH_3C_6H_2(NO_2)_3$ (Formation of TNT)

492. Calculate the percentage composition of propane, C_3H_8.

493. The weight of a liter of methane is 0.72. Calculate its vapor density, specific gravity, and molecular weight.

494. Any member of the paraffin (methane) series may be represented by the formula C_nH_{2n+2}. Determine the formula of that member of this series containing 18 atoms of carbon in its molecule.

495. Determine the percentage composition of all of the four chlorine substitution products of methane (CH_3Cl, CH_2Cl_2, $CHCl_3$, CCl_4).

496. A liter of ethane weighs 1.34 grams. Find its molecular weight, vapor density, and specific gravity.

497. Propane when vaporized gives a vapor density of 22. It contains 81.81% carbon and 18.19% hydrogen. From these data calculate its true formula.

498. 0.58 gram of acetylene gas occupies a volume, under standard conditions, of 500 cc. Determine its specific gravity, vapor density, molecular weight, and weight of 1.5 liters.

499. The vapor density of ethane was found to be 15. Determine the true formula of this compound which contains 80% carbon.

500. How many grams of oxygen will be necessary for the complete combustion of 3.2 grams of marsh gas?

501. Find the weights of each of the products formed in the complete combustion of 17 grams of camphene, $C_{10}H_{16}$.

502. What weight of iodine would be required to prepare 19.7 lb. of iodoform?

47. ALCOHOLS

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + \uparrow 2CO_2$ (Preparation of **ethyl alcohol** by the fermentation of glucose)
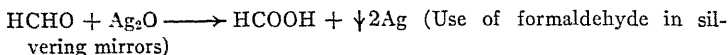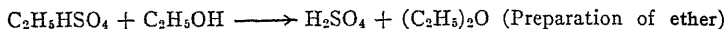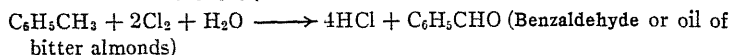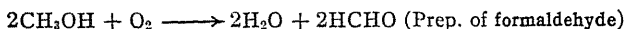
$2CH_3OH + O_2 \longrightarrow 2H_2O + 2HCHO$ (Formaldehyde, test for wood or **methyl alcohol**)

$C_2H_5OH + 6NaOH + 4I_2 \longrightarrow \downarrow CHI_3 + HCOONa + 5NaI + 5H_2O$ (Iodoform test for ethyl alcohol)

$C_6H_5OH + 3HNO_3 \longrightarrow C_6H_2OH(NO_2)_3 + 3H_2O$ (Preparation of picric acid from **phenol**)

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503. Determine the percentage composition of glycerine, $C_3H_5(OH)_3$, and wood alcohol, CH_3OH.

504. 167 cc. of alcohol vapor weigh 0.34 gram. It is composed of 52.2% carbon, 13% hydrogen, and 34.8% oxygen. Determine the true formula of this alcohol.

505. What weight of phenol (C_6H_5OH) can be obtained from 234 grams of benzene (C_6H_6)?

506. What weight of alcohol will be needed to prepare 197 lb. of iodoform?

507. What weight of formaldehyde could be theoretically obtained from 112 grams of denatured alcohol containing 2% wood alcohol?

508. 23 grams of ethyl alcohol are burned. What weights of CO_2 and H_2O are formed?

509. What weight of alcohol can be obtained by completely transforming 9 grams of glucose containing 10% water?

510. 100 grams of wine were treated with sodium hydroxide and iodine. 91.97 grams of iodoform were precipitated. What percentage of alcohol was present in the wine?

511. What weight of glycerine can be obtained from 89 lb. of beef fat whose formula might be considered to be $C_3H_5(C_{17}H_{35}COO)_3$? (See the fifth equation under Esters, page 144.)

512. A manufacturer must make 100 tons of picric acid. What weight of phenol will he require, and what will he have to pay for this at the price of 23¢ per pound?

513. What volume of carbon dioxide results from the fermentation of 4.5 grams of glucose?

514. Upon oxidation, methyl alcohol was changed to 500 cc. of formaldehyde. What weight of methyl alcohol was oxidized?

515. 5.8 grams of acetone were dissolved in 100 grams of water. The boiling point was raised 0.52° C. What is the molecular weight of acetone?

48. ALDEHYDES, KETONES, AND ETHERS

$2CH_3OH + O_2 \longrightarrow 2H_2O + 2HCHO$ (Prep. of formaldehyde)

$3HCHO \longrightarrow H_3C_3H_3O_3$ (Paraformaldehyde)

$C_6H_5CH_3 + 2Cl_2 + H_2O \longrightarrow 4HCl + C_6H_5CHO$ (Benzaldehyde or oil of bitter almonds)

$(CH_3COO)_2Ca \longrightarrow CaCO_3 + CH_3COCH_3$ (Formation of acetone)

$C_2H_5HSO_4 + C_2H_5OH \longrightarrow H_2SO_4 + (C_2H_5)_2O$ (Preparation of ether)

$HCHO + Ag_2O \longrightarrow HCOOH + \downarrow 2Ag$ (Use of formaldehyde in silvering mirrors)

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516. Determine the percentage composition of (a) acetone, (b) ethyl ether, and (c) formaldehyde.

517. A compound contains 40% carbon, 6.8% hydrogen, and 53.2% oxygen. Its vapor density is 14.95. Find the true formula of this compound.

518. 250 cc. of the vapor of ether weigh 0.83 gram under standard conditions. Calculate its vapor density, specific gravity, and molecular weight.

519. What weight of acetone can be prepared from 79 lb. of calcium acetate?

520. What weight of pure ethyl alcohol will be required to manufacture 37 lb. of ethyl ether?

521. A manufacturer must make 424 lb. of oil of bitter almonds. What weights of toluene ($C_6H_5CH_3$) and chlorine must he use?

522. What weight of formaldehyde will be required to precipitate 12 grams of silver from a silver solution, to cover the back of a mirror?

523. What volume of air will be required to oxidize sufficient wood alcohol to produce 5 grams of formaldehyde?

524. What volumes of carbon dioxide and water vapor are formed when 1.48 grams of ether are completely burned?

525. 1.5 grams of silver are precipitated out of a silver solution by formaldehyde as the reducing agent. What weight of HCHO was required?

49. ORGANIC ACIDS

Oxalic acid, $COOH \cdot COOH$ (Obtained from sawdust)
Tartaric acid, $H_2C_4H_4O_6$ (Obtained from fermentation of grapes)
Citric acid, $H_3C_6H_5O_7$ (Found in lemons and limes)
Stearic acid, $C_{17}H_{35}COOH$ (Obtained from fats)

$$C_2H_5OH + O_2 \longrightarrow CH_3COOH + H_2O \text{ (Acetic acid from ethyl alcohol)}$$
$$C_3H_5(C_{17}H_{35}COO)_3 + 3H_2O \longrightarrow C_3H_5(OH)_3 + 3C_{17}H_{35}COOH \text{ (Hydrolysis of fat)}$$

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526. Determine the percentage composition of citric acid and of tartaric acid.

527. How much Rochelle salt $(KNaC_4H_4O_6)$ could be prepared from 100 lb. of tartaric acid?

528. How much cream of tartar, $KHC_4H_4O_6$, could be prepared from 10 kg. of tartaric acid?

529. A compound contained hydrogen, oxygen, and carbon in the proportion of 4.6%, 67.2%, and 28.2%, respectively. Its molecular weight was found to be 150 by the depression of the freezing point method. Find its true formula.

530. A barrel of wine went sour and 10.3 lb. of acetic acid were found present. What weight of pure grain alcohol was oxidized?

531. What weight of ethyl alcohol on oxidation yielded 36.6 grams of acetic acid?

532. What weight of stearic acid can be made from a fat consisting entirely of glycerol stearate and weighing 4.45 lb.?

533. What weight of tartaric acid would be needed to make 64.6 lb. of tartar emetic whose formula is $KSbOC_4H_4O_6$?

534. Oxalic acid contains 26.8% carbon, 2.2% hydrogen, and 71% oxygen. Determine its simplest formula.

535. What volume of air would be required to change completely 2.3 kg. of ethyl alcohol into acetic acid?

536. The vapor density of acetic acid was found to be 30. Find (a) the weight of 40 cc. of its vapor, (b) its specific gravity, and (c) its molecular weight.

50. ESTERS

Preparation
$$CH_3COOH + C_2H_5OH \longrightarrow H_2O + CH_3COOC_2H_5$$
(Ethyl acetate)
$$HNO_3 + C_2H_5OH \longrightarrow H_2O + C_2H_5NO_3 \quad \text{(Ethyl nitrate)}$$
$$3HNO_3 + C_3H_5(OH)_3 \longrightarrow 3H_2O + C_3H_5(NO_3)_3 \quad \text{(Nitroglycerine)}$$
$$CH_3COOH + C_5H_{11}OH \longrightarrow H_2O + C_5H_{11}COOCH_3$$
(Amyl acetate or banana oil)

Chem. Prop.
$$C_3H_5(OOCH_{35}C_{17})_3 + 3H_2O \longrightarrow C_3H_5(OH)_3 + 3C_{17}H_{35}COOH$$
(Hydrolysis of glyceryl stearate or fat)
$$4C_3H_5(NO_3)_3 \longrightarrow 12CO_2 + 10H_2O + 6N_2 + O_2$$
(Decomposition of nitroglycerine) .

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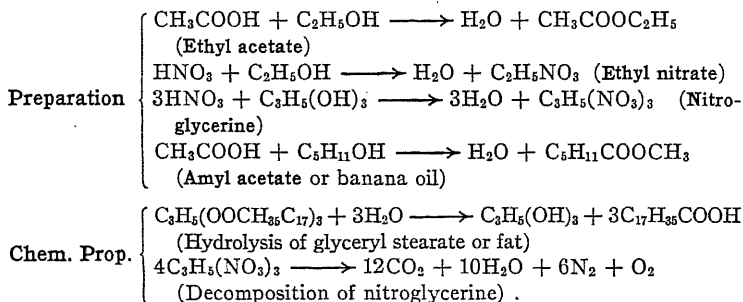
537. Determine the percentage composition of ethyl nitrate.

538. A compound contains 26.4% carbon, 15.4% nitrogen, 5.5% hydrogen, and 52.7% oxygen. Its molecular weight is found to be 91. What is its true formula?

539. It is required to prepare 110 grams of ethyl acetate. What weights of alcohol and acid will be needed?

540. What weight of nitric acid will be used in the making of 2270 tons of nitroglycerine?

541. What weight of glacial acetic acid would be required to prepare 13 lb. of amyl acetate (banana oil)?

542. What weight of ethyl alcohol would be needed for the production of 273 grams of ethyl nitrate?

543. How much glycerine will be needed for the manufacture of 1135 tons of nitroglycerine?

544. How much glycerine would be available from 108 lb. of a fat containing 70% glyceryl stearate?

545. Oil of wintergreen is made by the action of methyl alcohol (CH_3OH) and salicylic acid, $C_6H_4OHCOOH$. Determine the weights of the substances necessary for the manufacture of 10 lb. of this ester.

546. A manufacturer gets an order for 450 lb. of banana oil. What weights of amyl alcohol and acetic acid must he have to fill this order?
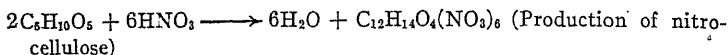
51. SOAPS

Lab. Prep. $\left\{\begin{array}{l} C_{17}H_{35}COOH + NaOH \longrightarrow H_2O + C_{17}H_{35}COONa \\ \text{(Sodium stearate, hard soap)} \\ C_{17}H_{35}COOH + KOH \longrightarrow H_2O + C_{17}H_{35}COOK \text{ (Potas-} \\ \text{sium stearate, soft soap)} \\ 2C_{17}H_{35}COONa + CaSO_4 \longrightarrow Na_2SO_4 + \downarrow (C_{17}H_{35}COO)_2Ca \\ \text{(Calcium stearate, insoluble soap)} \end{array}\right.$

Com. Prep. $\left\{\begin{array}{l} C_3H_5(C_{17}H_{35}COO)_3 + 3NaOH \longrightarrow 3NaC_{17}H_{35}COO \\ + C_3H_5(OH)_3 \text{ (Saponification of glyceryl stearate)} \\ C_3H_5(COOC_{17}H_{35})_3 + 3H_2O \longrightarrow 3HC_{17}H_{35}COO \\ + C_3H_5(OH)_3 \text{ (Hydrolysis of glyceryl stearate)} \end{array}\right.$

547. Determine the percentage composition of sodium stearate.

548. What weight of glycerine can be obtained from 1980 lb. of glyceryl stearate?

549. What weight of stearic acid can be obtained from 17.8 lb. of glyceryl stearate?

550. Determine the simplest formula of a fatty acid containing 76% carbon, 12.7% hydrogen, and 11.3% oxygen.

551. A soap contains 12.1% potassium, 67% carbon, 10.9% hydrogen, and 10% oxygen. What is its simplest formula?

552. What weight of $CaCl_2 \cdot 2H_2O$ will be needed to precipitate completely 10.2 grams of sodium stearate?

553. A soft soap is added to some hard water and results in the precipitation of 5.9 grams of magnesium stearate. What weight of $MgSO_4$ was present in the water?

554. The saponification value of a fat is the number of milligrams of KOH required to saponify 1 gram of the fat. What weight of KOH would be required to saponify 89 kg. of a fat whose composition might be represented as $C_3H_5(C_{17}H_{35}COO)_3$?

555. A gallon of hard water was treated with an excess of hard soap and 0.2 gram of calcium stearate precipitated. What weight of $CaSO_4$ was present in the water?

556. 1 liter of Clarke's Hardness Solution contains 2.29 grams of $CaCl_2$ in solution. What volume of this solution will be required to precipitate 4.58 grams of soft soap whose formula might be considered to be $C_{17}H_{35}COOK$?

52. CARBOHYDRATES

Starch, $(C_6H_{10}O_5)x$	$6CO_2 + 5\,H_2O \longrightarrow \uparrow 6O_2 + C_6H_{10}O_5$ (Photosynthesis)
Cellulose, $(C_6H_{10}O_5)y$	$C_6H_{10}O_5 \longrightarrow 6C + 5\,H_2O$ (Action of conc. H_2SO_4)
Glucose, $C_6H_{12}O_6$	$C_6H_{10}O_5 + H_2O \longrightarrow C_6H_{12}O_6$ (Hydrolysis of starch)
Sucrose, $C_{12}H_{22}O_{11}$	$C_{12}H_{22}O_{11} + H_2O \longrightarrow C_6H_{12}O_6 + C_6H_{12}O_6$ (Inversion of cane sugar)

$2C_6H_{10}O_5 + 6HNO_3 \longrightarrow 6H_2O + C_{12}H_{14}O_4(NO_3)_6$ (Production of nitrocellulose)

557. Determine the percentage composition of (a) cellulose, (b) sucrose, and (c) glucose.

558. What is the simplest formula of a carbohydrate which gave on analysis 42.1% carbon and 57.9% water?

559. A compound contained 40% carbon, 6.7% hydrogen, and 53.3% oxygen. 90 grams of this substance lowered the freezing point of 1000 grams of water to $-0.93°$ C. What is the true formula of this compound?

560. What weight of pure carbon can be obtained from 171 lb. of dry sucrose?

561. 12.6 grams of dextrose dissolved in 100 grams of water raised the boiling point $0.364°$ C. What is its molecular weight?

562. What weight of fructose $(C_6H_{12}O_6)$ can be obtained by the complete inversion of 6.84 grams of cane sugar?

563. A plant manufactured 4.05 grams of starch. What volume of oxygen did the plant liberate during the process?

564. It has been calculated that an average man exhales 450 liters of carbon dioxide in a day. Calculate the weight of starch a plant could manufacture from this CO_2.

565. In photosynthesis what volume of oxygen is liberated by the plant during its manufacture of 1 lb. of starch?

566. What weight of sucrose must be inverted to furnish 72 lb. each of glucose and fructose?

567. What weight of cotton, containing 98% pure cellulose, will be required to make 1188 tons of nitrocellulose, assuming the equation given above to represent the entire reaction?
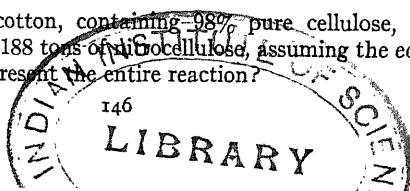
APPENDIX

INTERNATIONAL TABLE OF ATOMIC WEIGHTS OF THE CHEMICAL ELEMENTS (1925)

	Symbol	Atomic Number	Atomic Weight		Symbol	Atomic Number	Atomic Weight
Aluminum .	Al	13	26.97	Molybdenum	Mo	42	96.0
Antimony .	Sb	51	121.77	Neodymium	Nd	60	144.27
Argon . .	A	18	39.91	Neon . .	Ne	10	20.2
Arsenic . .	As	33	74.96	Nickel . .	Ni	28	58.69
Barium . .	Ba	56	137.37	Nitrogen .	N	7	14.008
Beryllium .	Be	4	9.02	Osmium . .	Os	76	190.8
Bismuth . .	Bi	83	209.00	Oxygen . .	O	8	16.000
Boron . .	B	5	10.82	Palladium .	Pd	46	106.7
Bromine . .	Br	35	79.916	Phosphorus	P	15	31.027
Cadmium .	Cd	48	112.41	Platinum .	Pt	78	195.23
Calcium . .	Ca	20	40.07	Potassium .	K	19	39.096
Carbon . .	C	6	12.000	Praseodym-			
Cerium . .	Ce	58	140.25	ium . .	Pr	59	140.92
Cesium . .	Cs	55	132.81	Radium . .	Ra	88	225.95
Chlorine . .	Cl	17	35.457	Radon . .	Rn	86	222.
Chromium .	Cr	24	52.01	Rhodium .	Rh	45	102.91
Cobalt . .	Co	27	58.94	Rubidium .	Rb	37	85.44
Columbium	Cb	41	93.1	Ruthenium .	Ru	44	101.7
Copper . .	Cu	29	63.57	Samarium .	Sm	62	150.43
Dysprosium	Dy	66	162.52	Scandium .	Sc	21	45.10
Erbium . .	Er	68	167.7	Selenium .	Se	34	79.2
Europium .	Eu	63	152.0	Silicon . .	Si	14	28.06
Fluorine . .	F	9	19.00	Silver . .	Ag	47	107.880
Gadolinium	Gd	64	157.26	Sodium . .	Na	11	22.997
Gallium . .	Ga	31	69.72	Strontium .	Sr	38	87.63
Germanium	Ge	32	72.60	Sulfur . .	S	16	32.064
Gold . . .	Au	79	197.2	Tantalum .	Ta	73	181.5
Hafnium .	Hf	72	178.3	Tellurium .	Te	52	127.5
Helium . .	He	2	4.00	Terbium .	Tb	65	159.2
Holmium .	Ho	67	163.4	Thallium .	Tl	81	204.39
Hydrogen .	H	1	1.008	Thorium .	Th	90	232.15
Indium . .	In	49	114.8	Thulium .	Tm	69	169.4
Iodine . .	I	53	126.932	Tin . . .	Sn	50	118.70
Iridium . .	Ir	77	193.1	Titanium .	Ti	22	48.1
Iron . . .	Fe	26	55.84	Tungsten .	W	74	184.0
Krypton .	Kr	36	82.9	Uranium .	U	92	238.17
Lanthanum	La	57	138.90	Vanadium .	V	23	50.96
Lead . . .	Pb	82	207.20	Xenon . .	Xe	54	130.2
Lithium . .	Li	3	6.940	Ytterbium .	Yb	70	173.6
Lutecium .	Lu	71	175.0	Yttrium . .	Y	39	88.9
Magnesium	Mg	12	24.32	Zinc . . .	Zn	30	65.38
Manganese .	Mn	25	54.93	Zirconium .	Zr	40	91.
Mercury .	Hg	80	200.61				

TABLE OF APPROXIMATE ATOMIC WEIGHTS
OF THE COMMON ELEMENTS

Element	Symbol	Atomic Weight	Common Valence	Element	Symbol	Atomic Weight	Common Valence
Aluminum	Al	27	III	Iron	Fe	56	II, III
Antimony	Sb	122	III	Lead	Pb	207	II
Arsenic	As	75	III	Lithium	Li	7	I
Barium	Ba	137	II	Magnesium	Mg	24	II
Bismuth	Bi	209	III	Manganese	Mn	55	II, IV
Boron	B	11	III	Mercury	Hg	200	I, II
Bromine	Br	80	I	Nickel	Ni	59	II
Cadmium	Cd	112	II	Nitrogen	N	14	III, V
Calcium	Ca	40	II	Oxygen	O	16	II
Carbon	C	12	IV	Phosphorus	P	31	III, V
Chlorine	Cl	35.5	I	Platinum	Pt	195	IV
Chromium	Cr	52	III	Potassium	K	39	I
Cobalt	Co	59	II	Silicon	Si	28	IV
Copper	Cu	64	I, II	Silver	Ag	108	I
Fluorine	F	19	I	Sodium	Na	23	I
Gold	Au	197	I, III	Strontium	Sr	87	II
Helium	He	4	0	Sulfur	S	32	II, IV
Hydrogen	H	1	I	Tin	Sn	119	II, IV
Iodine	I	127	I	Zinc	Zn	65	II

THE METRIC SYSTEM

$$1 \text{ decimeter (dm.)} = 0.1 \text{ meter (m.)}$$
$$1 \text{ centimeter (cm.)} = 0.01 \text{ meter (m.)}$$
$$1 \text{ millimeter (mm.)} = 0.001 \text{ meter (m.)}$$
$$1 \text{ kilometer (km.)} = 1000 \text{ meters (m.)}$$

$$1 \text{ decigram (dg.)} = 0.1 \text{ gram (g.)}$$
$$1 \text{ centigram (cg.)} = 0.01 \text{ gram (g.)}$$
$$1 \text{ milligram (mg.)} = 0.001 \text{ gram (g.)}$$
$$1 \text{ kilogram (kg.)} = 1000 \text{ grams (g.)}$$

UNIT EQUIVALENTS (approximate)

1 inch (in.)	= 2.54 centimeters (cm.)
1 square inch (sq. in.)	= 6.45 square centimeters (sq. cm.)
1 square meter (m.)	= 10.76 square feet (sq. ft.)
1 cubic inch (cu. in.)	= 16.4 cubic centimeters (cc.)
1 cubic foot (cu. ft.)	= 28.3 liters (l.)
1 cubic foot (cu. ft.)	= 7.48 gallons (gal.)
1 liter (l.)	= 61 cubic inches (cu. in.)
1 liter (l.)	= 1.06 quarts (qt.)
1 gallon (gal.)	= 231 cubic inches (cu. in.)
1 cubic meter (cu. m.)	= 1.31 cubic yards (cu. yd.)
1 cubic meter (cu. m.)	= 35.32 cubic feet (cu. ft.)

1 gram (g.)	= 15.43 grains (gr.)
1 ounce (oz.) Avoirdupois	= 28.35 grams (g.)
1 kilogram (kg.)	= 2.2 pounds (lb.)
1 ton (T.), short, 2000 lb.	= 907.2 kilograms (kg.)
1 ton (T.), long, 2240 lb.	= 1016 kilograms (kg.)
1 liter of water	= 2.2 pounds (lb.)
1 cubic foot of water	= 62.4 pounds (lb.)
1 gallon of water	= 8.35 pounds (lb.)
1 atmosphere pressure	= 1033 grams per square centimeter

On the **Centigrade** scale, the zero point is the height of the mercury when the thermometer is immersed in a mixture of ice and water when the atmospheric pressure is 760 mm. The 100 mark is that point representing the height of the mercury when the thermometer is immersed in steam vapor under the same condition of pressure. On the **Fahrenheit** scale, the freezing point of water is marked at 32° and the boiling point of water at 212°, making the absolute zero on this scale − 459.4°. On the **Absolute** scale, the absolute zero is − 273° C. The boiling point of water reads 373° on this scale (Fig. 9).

Fahrenheit   Centigrade   Absolute
thermometer thermometer   scale
scale   scale

FIG. 9.

Thermometer Conversion Rules

1. To convert Centigrade readings to the corresponding Fahrenheit readings, multiply the Centigrade reading by 1.8 and add 32.

   EXAMPLE. What is the Fahrenheit reading corresponding to 18° C.?

   $$18 \times 1.8 + 32 = 64.4° \text{ F.}$$

2. To convert Fahrenheit readings to the corresponding Centigrade readings, subtract 32 degrees from the Fahrenheit reading and divide by 1.8.

   EXAMPLE. What is the Centigrade reading corresponding to 100° F.?

   $$\frac{100 - 32}{1.8} = \frac{68}{1.8} = 37.77° \text{ C.}$$

3. To convert Centigrade to Absolute scale readings, add 273 to the Centigrade.

> EXAMPLE. What is the Absolute scale reading corresponding to $-43°$ C.?
>
> $$-43° + 273° = 230° \text{ Absolute.}$$

4. To convert Fahrenheit to Absolute scale readings, first convert to Centigrade reading and then add 273°.

> EXAMPLE. What is the Absolute scale reading corresponding to 68° F.?
>
> $$\frac{68 - 32}{1.8} + 273 = 20 + 273 = 293° \text{ Absolute.}$$

APPROXIMATE SPECIFIC HEATS OF THE COMMON ELEMENTS

(Measured at room temperature)

ELEMENT	SPECIFIC HEAT	ELEMENT	SPECIFIC HEAT
Aluminum	0.215	Gold	0.030
Antimony	0.050	Iron	0.115
Arsenic	0.075	Lead	0.030
Barium	0.060	Magnesium	0.225
Bismuth	0.035	Manganese	0.095
Boron	0.305	Mercury	0.035
Cadmium	0.055	Nickel	0.095
Calcium	0.155	Platinum	0.030
Carbon	0.205	Silicon	0.125
Chromium	0.085	Silver	0.055
Cobalt	0.085	Tin	0.055
Copper	0.085	Zinc	0.090

SPECIFIC GRAVITY OF SULFURIC ACID SOLUTIONS AT 15° C.

(Per cent = grams of acid per 100 grams solution)

Specific Gravity	Per Cent H₂SO₄	Specific Gravity	Per Cent H₂SO₄	Specific Gravity	Per Cent H₂SO₄
1.03	4.49	1.40	50.11	1.64	71.99
1.07	10.19	1.42	52.15	1.66	73.64
1.11	15.71	1.44	54.07	1.68·	75.42
1.15	20.91	1.46	55.97	1.70	77.17
1.19	26.04	1.48	57.83	1.72	78.92
1.23	31.11	1.50	59.70	1.74	80.68
1.27	35.71	1.52	61.59	1.76	82.44
1.31	40.35	1.54	63.43	1.78	84.50
1.32	41.50	1.56	65.08	1.80	86.90
1.34	43.74	1.58	66.71	1.82	90.05
1.36	45.88	1.60	68.51	1.83	92.10
1.38	48.00	1.62	70.32	1.84	99.20

SPECIFIC GRAVITY OF HYDROCHLORIC ACID SOLUTIONS AT 15° C.

(Per cent = grams of acid per 100 grams solution)

Specific Gravity	Per Cent HCl	Specific Gravity	Per Cent HCl	Specific Gravity	Per Cent HCl
1.01	2.14	1.08	16.15	1.15	29.57
1.02	4.13	1.09	18.11	1.16	31.52
1.03	6.15	1.10	20.01	1.17	33.46
1.04	8.16	1.11	21.92	1.18	35.39
10.5	10.17	1.12	23.82	1.19	37.23
1.06	12.19	1.13	25.75	1.195	38.16
1.07	14.17	1.14	27.66	1.20	39.11

SPECIFIC GRAVITY OF NITRIC ACID SOLUTIONS AT 15° C.

(Per cent = grams of acid per 100 grams solution)

Specific Gravity	Per Cent HNO₃	Specific Gravity	Per Cent HNO₃	Specific Gravity	Per Cent HNO₃
1.01	1.90	1.21	33.82	1.41	67.50
1.03	5.50	1.23	36.78	1.43	72.17
1.05	8.99	1.25	39.82	1.45	77.28
1.07	12.33	1.27	42.87	1.46	79.98
1.09	15.53	1.29	45.95	1.47	82.90
1.11	18.67	1.31	49.07	1.48	86.05
1.13	21.77	1.33	52.37	1.49	89.60
1.15	24.84	1.35	55.79	1.50	94.09
1.17	27.88	1.37	59.39	1.51	98.10
1.19	· 30.88	1.39	63.23	1.52	99.67

SPECIFIC GRAVITY OF AMMONIA WATER SOLUTIONS AT 15° C.

(Per cent = grams of NH_3 per 100 grams solution)

Specific Gravity	Per Cent NH_3	Specific Gravity	Per Cent NH_3	Specific Gravity	Per Cent NH_3
0.882	34.95	0.922	21.12	0.962	9.35
0.886	33.25	0.926	19.87	0.966	8.33
0.890	31.75	0.930	18.64	0.970	7.31
0.894	30.37	0.934	17.42	0.974	6.30
0.898	29.01	0.938	16.22	0.978	5.30
0.902	27.65	0.942	15.04	0.982	4.30
0.906	26.31	0.946	13.88	0.986	3.30
0.910	24.99	0.950	12.74	0.990	2.31
0.914	23.68	0.954	11.60	0.994	1.37
0.918	22.39	0.958	10.47	0.998	0.45

CONCENTRATION AND SPECIFIC GRAVITY OF COMMON ACIDS AND BASES

Reagent	Specific Gravity	Per Cent by Weight
Conc. HCl	1.20	39%
Dilute HCl	1.05	10%
Conc. H_2SO_4	1.84	98%
Dilute H_2SO_4	1.09	13%
Conc. HNO_3	1.42	70%
Dilute HNO_3	1.11	19%
Conc. NH_4OH	0.90	28%
Dilute NH_4OH	0.96	10%
5 N Acetic acid	1.04	30%

Commercial NaOH contains 10% H_2O
Commercial KOH contains 20% H_2O

TABLE OF SOME COMMON FACTORS FOR QUANTITATIVE ANALYSIS

WEIGHED AS	REQUIRED	FACTOR
Al_2O_3	Al	0.530
NH_4Cl	NH_3	0.318
$Mg_2As_2O_7$	As_2O_3	0.637
$BaSO_4$	$BaCl_2$	0.892
AgBr	Br	0.431
$CaSO_4$	CaO	0.412
CO_2	$CaCO_3$	2.274
AgCl	NaCl	0.408
$PbCrO_4$	Cr_2O_3	0.235
CuO	Cu	0.799
Ag	CN	0.241
AgI	HI	0.545
$PbSO_4$	PbS	0.789
$Mg_2P_2O_7$	$MgSO_4$	1.081
$MgSO_4$	MgO	0.335
HgO	HgS	1.074
$(NH_4)_2PtCl_6$	NO_3	0.279
P_2O_5	PO_4	1.338
K_2PtCl_6	Pt	0.402
SiF_4	SiO_2	0.578
NaCl	Na_2O	0.530
Na_2CO_3	Na_2O	0.585
$BaSO_4$	S_2O_3	0.240
SnO_2	$SnCl_2$	1.258
ZnO	ZnS	1.197

PRICES OF COMMON CHEMICALS

(Prevailing in the New York market, March, 1926)

ACIDS

Acetic acid, 56%	$6.09, 100 lb.
Boric acid	9½¢ per lb.
Hydrochloric, 35%	90¢, 100 lb.
Hydrofluoric, 30%	6¢ per lb.
Nitric, 56%	$5.75, 100 lb.
Sulfuric, 98%	$1.25, 100 lb.

BASES

Ammonia water, 90%	6½¢ per lb.
Slaked lime	1¢ per lb.
Caustic soda	$3.10 per 100 lb.
Caustic potash	7½¢ per lb.

METALS

Aluminum	28¢ per lb.
Antimony	19¢ per lb.
Arsenic	45¢ per lb.
Bismuth	$3.35 per lb.
Copper	14¾¢ per lb.
Gold	$20.67 per troy oz.
Lead	9⅜¢ per lb.
Magnesium	85¢ per lb.
Mercury	$89 per 75 lb.
Nickel	34¢ per lb.
Platinum	$120 per oz.
Silver	65¢ per oz.
Sodium	27¢ per lb.
Tin	65¼¢ per lb.
Zinc	8⅜¢ per lb.

NON-METALS

Bromine	47¢ per lb.
Chlorine	5½¢ per lb.
Helium	6¢ per cu. ft.
Hydrogen	2¢ per cu. ft.
Iodine	$4.65 per lb.
Nitrogen	2½¢ per cu. ft.
Oxygen	85¢ per 100 cu. ft.
Phosphorus (red)	68¢ per lb.
Sulfur, roll (mines)	$17 per ton
Flowers of Sulfur	$3 per 100 lb.

SALTS

Ammonium chloride	5¼¢ per lb.
Ammonium sulfate	$2.70, 100 lb.
Borax	5¢ per lb.
Bleaching powder	$2.00, 100 lb.
Calomel	$1.37 per lb.
Chrome alum	$5.25, 100 lb.
Copper sulfate	4¼¢ per lb.
Epsom salts	$2.00, 100 lb.
Ferrous sulfide	$2.50, 100 lb.
Fluor-spar	$25 per ton
Lead acetate	15¢ per lb.
Mercury bichloride	$1.31 per lb.
Potassium carbonate	5½¢ per lb.
Potassium chlorate	8½¢ per lb.
Potassium chloride	$34.55 per ton
Potassium permanganate	14½¢ per lb.
Silver nitrate	45¢ per oz.
Sodium bicarbonate	$2, 100 lb.
Sodium bromide	48¢ per lb.
Sodium carbonate	$1.30, 100 lb.
Sodium chlorate	5¾¢ per lb.
Sodium chloride	$12 per ton
Sodium nitrate	$2.72 per 100 lb.
Sodium silicate	.75¢ per 100 lb.
Zinc sulfate	3½¢ per lb.

MISCELLANEOUS

Alcohol, ethyl	$4.75 per gal.
Calcium carbide	4¼¢ per lb.
Carbon disulfide	6¢ per lb.
Carbon tetrachloride	6½¢ per lb.
Chloroform	28¢ per lb.
Cream of tartar	22¢ per lb.
Cyanamid	$1.90 per ammonia unit
Ether	16¢ per lb.
Ethyl acetate	$1.15 per gal.
Glycerine	24¢ per lb.
Hydrogen peroxide (25 v)	7¢ per lb.
Paris green	19¢ per lb.
Phenol	22¢ per lb.
Toluene	35¢ per gal.
White arsenic	3¼¢ per lb.
White lead	10¾¢ per lb.
Wood alcohol	57¢ per gal.

OXIDES

Barium peroxide	13¢ per lb.
Carbon dioxide	6¢ per lb.
Lime	$1.05, 100 lb.
Manganese dioxide	$80 per ton
Sand	$18 per ton
Sodium peroxide	27¢ per lb.
Sulfur dioxide	8¢ per lb.

PRACTICE TABLE OF COMPOUNDS FROM VALENCIES

	ACETATE	BICARBON-ATE	BRO-MIDE	CAR-BONATE	CHLORATE	CHLO-RIDE
Aluminum						
Ammonium						
Barium	$Ba(C_2H_3O_2)_2$	$Ba(HCO_3)_2$	$BaBr_2$	$BaCO_3$	$Ba(ClO_3)_2$	$BaCl_2$
Bismuth						
Calcium						
Chromium						
Cupric						
Gold						
Hydrogen						
Ferrous						
Ferric						
Lead						
Lithium						
Magnesium						
Mercurous						
Mercuric						
Potassium						
Silver						
Sodium						
Stannous						
Zinc						

	Io-DIDE	NITRATE	NITRITE	Ox-IDE	PHOS-PHATE	SUL-FATE	SUL-FITE	SUL-FIDE
Aluminum								
Ammonium								
Barium	BaI_2	$Ba(NO_3)_2$	$Ba(NO_2)_2$	BaO	$Ba_3(PO_4)_2$	$BaSO_4$	$BaSO_3$	BaS
Bismuth								
Calcium								
Chromium								
Cupric								
Gold								
Hydrogen								
Ferrous								
Ferric								
Lead								
Lithium								
Magnesium								
Mercurous								
Mercuric								
Potassium								
Silver								
Sodium								
Stannous								
Zinc								

PROBLEMS BASED ON THE THEORY OF IONIZATION

WE have noted (pages 64–66) that the gram-molecular weights of sucrose and phenol raise the boiling point and lower the freezing point of water to 100.52° C. and − 1.87° C., respectively. The gram-molecular weights of NaCl, NaOH, and HNO$_3$ will each raise the boiling point and lower the freezing point of water almost twice these amounts. The gram-molecular weights of Na$_2$SO$_4$ and H$_2$SO$_4$ each in a liter of water will produce results nearly three times as great. Now, since the depression of the freezing point and the elevation of the boiling point depend upon the number of particles of solute dissolved in the solution, why should not the gram-molecular weights of all substances which contain the same number of particles have the same effect on the freezing and the boiling points?

Another curious problem presents itself. Sugar and phenol when dissolved in water do not conduct an electric current. They are *non-electrolytes*. Solutions of NaCl, HCl, NaOH, Na$_2$SO$_4$, and H$_2$SO$_4$ are all good electrolytes. There seems to be some relationship between the conductivity of a solution and the power of a substance to affect **abnormally** the freezing point and the boiling point of solutions. By actual experimentation it has been found that those substances which give a **normal** lowering of the freezing point and rise of the boiling point are **non-electrolytes**, while those that **conduct** the current give **abnormal** results.

To explain the above problems a young Swedish chemist, Svante Arrhenius, advanced his *Theory of Electrolytic Dissociation or Ionization*, in 1887. His theory, briefly put, stated that *when a crystalloidal solute rendered a solution a conductor of electricity, the current was carried by particles called ions carrying definite electric charges proportional only to their*

valencies. These ions were produced by the breaking down or dissociation of the molecules of the solute into positively charged particles and negatively charged particles.

Thus water ionized NaCl into sodium ions, written Na$^+$, and chlorine ions, written Cl$^-$. Sulfuric acid dissociated into H$^+$, H$^+$, and SO_4^{--}, potassium hydroxide into K$^+$ and OH^-, while sugar and phenol did not dissociate at all. Since the current is carried by ions, a sugar solution could not conduct the current. Since the number of particles (ions) actually present in the NaCl solution is double that of the sugar solution, NaCl lowers the freezing point of water twice as much as sugar. Ions differ in their properties from atoms because of the charges which ions carry.

Electrolytes do not all dissociate to the same extent. Acids all contain hydrogen ions in solution, and acid properties are due to the presence of these hydrogen ions. In fact, the number of these H$^+$ determines the strength of the acid. Thus HNO$_3$, which is more than 90% ionized, is much more active than acetic acid, which is only 1% ionized. The facility with which equi-molar solutions of different substances conduct the current depends chiefly upon the *degree of ionization*. Therefore, by means of conductivity measurements we can determine the degree of ionization of a substance in solution.

A. *Degree of ionization*

Since the conductivity of a solution and its degree of dissociation are intimately related, we may express this relationship by the·equation

$$a = \frac{\lambda v}{\lambda \infty} = \text{degree of dissociation or ionization,}$$

where λv is the equivalent conductivity of a gram-equivalent
   of the substance in v liters of water,

and λ_∞ is the equivalent conductivity of a gram-equivalent of the substance at infinite dilution — that is, when the dissociation of the electrolyte is complete. Both λv and λ_∞ are expressed in *reciprocal ohms*.[1]

By measuring, then, both λv and λ_∞, or rather their reciprocals, we can determine the proportion of molecules completely ionized in solution. A table showing the degree of ionization of some common chemicals follows :

DEGREE OF IONIZATION IN 0.1 N SOLUTIONS AT 18° C.

Hydrochloric acid	92%	Potassium chloride	86%
Nitric acid	92	Ammonium chloride	85
Sulfuric acid	61	Sodium chloride	84
Phosphoric acid	27	Sodium nitrate	83
Hydrofluoric acid	15	Potassium acetate	83
Tartaric acid	8	Silver nitrate	81
Acetic acid	1.3	Sodium bicarbonate	78
Carbonic acid	0.17	Barium chloride	77
Boric acid	0.01	Potassium sulfate	72
		Sodium tartrate	69
Potassium hydroxide . . .	91	Zinc sulfate	40
Sodium hydroxide	91	Copper sulfate	39
Barium hydroxide	77	Mercuric chloride	1
Ammonium hydroxide . . .	1.3	Mercuric cyanide	Minute

EXAMPLE. The equivalent conductivity of KCl at 18° C. is 130.1 at infinite dilution, and 112 in a 0.1 N solution. What is its degree of ionization in 0.1 N solution?

$$a = \frac{\lambda v}{\lambda_\infty} = \frac{112}{130.1} = 0.86 \text{ or } 86\%$$

[1] Every conductor offers some electrical resistance. The greater the conductance the less the resistance. Resistance is therefore the reciprocal of conductance. The practical unit of resistance is the *ohm*, which is the resistance offered to a current by a thread of mercury at 0° C., 1 sq. mm. in cross-section and 106.3 cm. in length. The unit of conductance is the reciprocal ohm or mho.

Problems

1. The equivalent conductivity of acetic acid at 18° C. is 347 at infinite dilution, and 4.67 in a tenth normal solution. What is the degree of dissociation of acetic acid in 0.1 N solution?
2. The equivalent conductivity of a sodium acetate solution of 0.08 N is 63.4. At infinite dilution it is 78.1. Calculate the degree of ionization of this sodium acetate.
3. At 18° C. the equivalent conductivity of LiCl is 101.4 mhos at infinite dilution. For a 0.01N solution it is 93.6. What is the degree of ionization of this lithium chloride?
4. The equivalent conductivity at 18° C. and infinite dilution of HI is 384 mhos. The equivalent conductivity of the 0.5 N solution is 345. What is its degree of ionization?
5. The equivalent conductivity of HCl at 18° C. is 379 at infinite dilution, and 351 in 0.1 normal solution. Find the value of $\propto$.
6. The equivalent conductivity of potassium acetate at 18° C. and infinite dilution is 100. For a half normal solution it is equal to 71.6. What is the degree of ionization of $KC_2H_3O_2$?
7. At infinite dilution the equivalent conductivity of KOH is 249. For a 0.2 N solution it is 206. Calculate its degree of dissociation.
8. The equivalent conductivity of acetic acid is 1.32 mhos for a normal solution. Its equivalent conductivity at infinite dilution is 350. What is its degree of dissociation for a normal solution?
9. The equivalent conductivity of a normal HCl solution is 301 mhos. At infinite dilution it is equal to 380. Calculate its degree of ionization for a normal solution.

LAW OF MASS ACTION AS APPLIED TO REACTIONS BETWEEN ELECTROLYTES

The direction in which a reversible reaction will go depends upon the *concentrations*, expressed in gram moles per liter, of all the substances involved in the reaction. This behavior is expressed by the *Law of Mass Action*, first advanced by Guldberg and Waage in 1864. The equation for this law may be written as

$$K = \frac{[A] \times [B]}{[C]},$$

where $[A]$, $[B]$, and $[C]$ are the concentrations of the reacting

substances, and K is the rate at which the reaction would proceed were the reacting substances originally present constantly maintained at unit concentration. The value of K for *each action* is the same. Whenever one of the reacting substances is removed from the sphere of the reaction, the reaction proceeds in one direction to completion. This occurs when (*a*) a gas is liberated, (*b*) a precipitate is formed, or (*c*) water is formed, since the ionic concentrations of these three classes of substances become zero.

The most common reactions are those which occur between electrolytes where concentration of ions are considered. Ionization is an excellent example of a reversible reaction. When NaCl dissolves in water, Na^+ and Cl^- are formed, and as they move about in solution they frequently meet and re-form NaCl molecules. Soon they reach a state of equilibrium which is dependent almost entirely upon the amount of solvent.

B. *Solubility product*

From the Law of Mass Action it follows that for a *saturated solution* of a *difficultly soluble salt*, such as silver acetate,
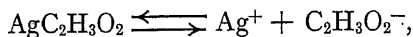
$$AgC_2H_3O_2 \rightleftharpoons Ag^+ + C_2H_3O_2^-,$$

the product of the ionic concentrations is a constant, called the *Solubility Product* (*S. P.*). The concentration is expressed in gram moles per liter of solution. Thus

$$[Ag^+] \times [C_2H_3O_2^-] = S. P. \text{ (constant)}$$

SOLUBILITY PRODUCTS OF SOME COMMON SALTS

$BaCO_3$	1.9×10^{-9}	PbS	4×10^{-28}
BaC_2O_4	1.2×10^{-7}	HgS	4×10^{-54}
$BaSO_4$	1.0×10^{-10}	AgBr	4×10^{-23}
$CaCO_3$	2.8×10^{-9}	AgCl	2×10^{-10}
CuS	8.5×10^{-45}	ZnS	1×10^{-23}

EXAMPLE. Analysis shows that the concentration of a saturated solution of silver acetate at 18° C. is approximately 0.06.   Find its solubility product.

The concentration of both $[Ag^+]$ and $[C_2H_3O_2^-]$ is 0.06.   In such a dilute solution the dissociation of the silver acetate will be practically complete. Hence we can write

$$S.P. = (0.06) \times (0.06) = 0.0036.$$

Problems

10. The solubility of silver chloride is 0.00016 grams per liter.   What is its solubility product?
11. The solubility of barium sulfate is 1×10^{-5} grams per liter.   Determine its ion product concentration (S. P.).
12. The solubility of Ag_2CrO_4 is 2.5×10^{-2}.   Calculate its solubility product.
13. The solubility of $Pb_3(PO_4)_2$ is 1.4×10^{-4}.   What is its ion product concentration?
14. The solubility product of AgCl is 2×10^{-10}.   Calculate its solubility in grams per liter.
15. The solubility of calcium chromate in gram molecules per liter at room temperature is 0.03.   Calculate its S. P.

THE important thing to remember about balancing equations is to attack the problem in a definite way. While there is no one way of balancing all chemical equations, the student, by practice, will soon learn to find the easiest scheme to balance each particular equation. The following schemes will help balance most of the common equations.

1. **Pick out the compound with the largest number of atoms and proceed as follows:**

$$KBr + H_2SO_4 + MnO_2 \longrightarrow K_2SO_4 + MnSO_4 + H_2O + Br_2.$$
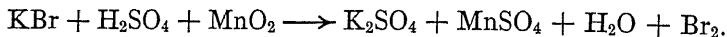
Let us start with K_2SO_4. This molecule has 2 atoms of K; therefore 2 atoms of K must be present on the left side of the equation. Since we cannot change the number of atoms in KBr, we place the coefficient 2 in front of the formula, **2KBr**. There are 2 sulfate radicals SO_4 on the right of the equation, one in $MnSO_4$ and the other in K_2SO_4. Therefore we add the coefficient 2 in front of H_2SO_4. The equation may now be written as

$$2KBr + 2H_2SO_4 + MnO_2 \longrightarrow K_2SO_4 + MnSO_4 + H_2O + Br_2.$$
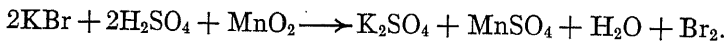
Now we have 4 atoms of H on the left side of the equation and only 2 on the right. Hence we add the coefficient 2 in front of H_2O. This gives us 2 atoms of **oxygen** on the right side (irrespective of the O in SO_4), which is the same as the number of oxygen atoms on the left side of the equation (irrespective of the O in SO_4). The equation may now be written:

$$2KBr + 2K_2SO_4 + MnO_2 \longrightarrow K_2SO_4 + MnSO_4 + 2H_2O + Br_2.$$
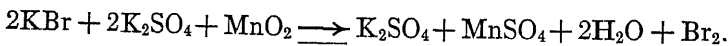
Now **check** the equation to see whether there is the same number of atoms of **each** element on **each** side of the equation.

Remember that, as a rule, radicals do not change during a chemical transformation.

EXERCISES.   Balance the following equations:

1. $CaO + C \longrightarrow CaC_2 + CO$

2. $H_2O + N_2O_5 \longrightarrow HNO_3$

3. $Mg + HCl \longrightarrow MgCl_2 + H_2$

4. $SiO_2 + C \longrightarrow SiC + CO$

5. $Fe_2O_3 + Al \longrightarrow Al_2O_3 + Fe$

6. $NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$

7. $AgNO_3 + H_2S \longrightarrow Ag_2S + HNO_3$

8. $CaC_2 + H_2O \longrightarrow C_2H_2 + Ca(OH)_2$

9. $Pb(NO_3)_2 + K_2CrO_4 \longrightarrow PbCrO_4 + KNO_3$

10. $Al_2(SO_4)_3 + NH_4OH \longrightarrow Al(OH)_3 + (NH_4)_2SO_4$

11. $C_3H_5(OH)_3 + HNO_3 \longrightarrow C_3H_5(NO_3)_3 + H_2\dot{O}$

12. $C_6H_{12}O_6 \longrightarrow C_2H_5OH + CO_2$

13. $K_3Fe(CN)_6 + FeCl_2 \longrightarrow Fe_3[Fe(CN)_6]_2 + KCl$

14. $K_4Fe(CN)_6 + FeCl_3 \longrightarrow Fe_4[Fe(CN)_6]_3 + KCl$

15. $Ca_3(PO_4)_2 + SiO_2 + C \longrightarrow CaSiO_3 + CO + P$

2. Use the atom of a gas rather than its molecule in balancing, and then make the necessary changes as follows:

$$C_6H_6 + O \longrightarrow CO_2 + H_2O$$
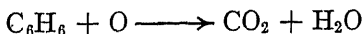
On the left side of the equation there are 6 carbon atoms and

6 hydrogen atoms. Therefore we ought to have $6CO_2$ and $3H_2O$, or,

$$C_6H_6 + O \longrightarrow 6CO_2 + 3H_2O$$
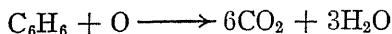
On the right of the equation we now have $12 + 3$ or 15 atoms of oxygen. Hence on the left side we should have 15 atoms of oxygen. The equation now becomes

$$C_6H_6 + 15O \longrightarrow 6CO_2 + 3H_2O$$
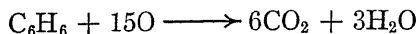
But oxygen has **2 atoms to the molecule**, therefore

$$C_6H_6 + 15O_2 \longrightarrow 6CO_2 + 3H_2O.$$
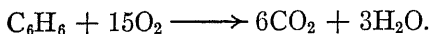
Since we have multiplied the number of oxygen atoms by 2, we should do the same with all the remaining substances in the equation. The balanced equation is therefore

$$2C_6H_6 + 15O_2 \longrightarrow 12CO_2 + 6H_2O.$$
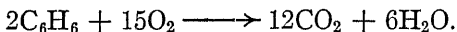
EXERCISES. Balance the following by inserting the proper coefficients:

16. $C + \quad O \longrightarrow \quad CO$

17. $Fe + \quad O \longrightarrow \quad Fe_2O_3$

18. $P + \quad O \longrightarrow \quad P_2O_5$

19. $Na + \quad H_2O \longrightarrow \quad NaOH + \quad H$

20. $SO_2 + \quad O \longrightarrow \quad SO_3$

21. $Fe + \quad O \longrightarrow \quad Fe_3O_4$

22. $Sb + \quad Cl \longrightarrow \quad SbCl_3$

23. $Mg + \quad N \longrightarrow \quad Mg_3N_2$

24. $N + \quad H \longrightarrow \quad NH_3$

25. $H_2S + \quad O \longrightarrow \quad H_2O + \quad SO_2$
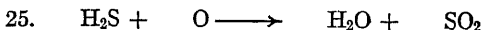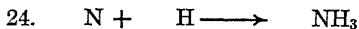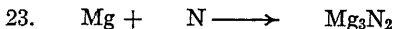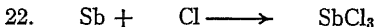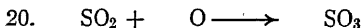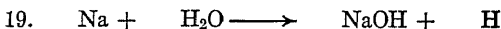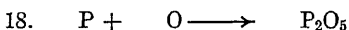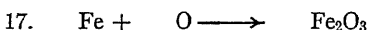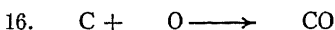
26. $KClO_3 \longrightarrow KCl + O$

27. $C_2H_2 + O \longrightarrow CO_2 + H_2O$

28. $CH_4 + O \longrightarrow CO_2 + H_2O$

29. $Fe + H_2O \longrightarrow Fe_3O_4 + H$

30. $Al + NaOH \longrightarrow Na_3AlO_3 + H$

3. Use the acid and base rather than their anhydrides and then make the necessary changes as follows:

Hot concentrated sulfuric acid is a strong oxidizing agent and when it reacts with copper is itself reduced to sulfurous acid, H_2SO_3; thus,

$$Cu + H_2SO_4 \longrightarrow CuSO_4 + H_2O + H_2SO_3.$$
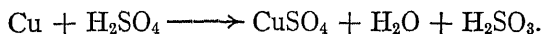
H_2SO_3, however, is unstable and at the temperature of the reaction breaks down into H_2O, and SO_2, its anhydride. Hence the equation is now

$$Cu + H_2SO_4 \longrightarrow CuSO_4 + H_2O + SO_2 + H_2O$$

Since we now have $2H_2O$, we shall need $2H_2SO_4$ and the balanced equation becomes

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$
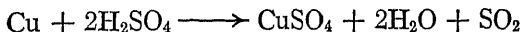
Carbonic acid is also unstable and breaks down into CO_2 and H_2O.

Similarly, ammonium hydroxide breaks down into NH_3 and H_2O.

EXERCISES. Balance the following by using the proper anhydrides and coefficients:

31. $Na_2SO_3 + H_2SO_4 \longrightarrow Na_2SO_4 + (H_2SO_3)$

32. $CaCO_3 + HCl \longrightarrow CaCl_2 + (H_2CO_3)$

33. $Ca(OH)_2 +$ $NH_4Cl \longrightarrow$ $CaCl_2 +$ (NH_4OH)

34. $CaCO_3 +$ $H_2SO_4 \longrightarrow$ $CaSO_4 +$ (H_2CO_3)

35. $Ba(OH)_2 +$ $(NH_4)_2SO_4 \longrightarrow$ $BaSO_4 +$ (NH_4OH)

36. $Al(OH)_3 + \cdot$ $(NH_4)_2SO_4 \longrightarrow$ $Al_2(SO_4)_3 +$ (NH_4OH)

37. $NaHCO_3 +$ $HKC_4H_4O_6 \longrightarrow$ $NaKC_4H_4O_6 +$ (H_2CO_3)

38. $Ag +$ $H_2SO_4 \longrightarrow$ $Ag_2SO_4 +$ $(H_2SO_3) +$ H_2O

39. $Sn +$ $H_2SO_4 \longrightarrow$ $\cdot Sn(SO_4)_2 +$ $(H_2SO_3) +$ H_2O

40. $H_2O_2 +$ $(H_2SO_3) \longrightarrow$ $H_2SO_4 +$ H_2O

4. Sometimes no amount of ordinary manipulation will enable the student to balance an equation within a reasonable length of time. In such cases it is best to **memorize some of the coefficients and work out the rest of the coefficients.**

The equation $Cu + HNO_3 \longrightarrow Cu(NO_3)_2 + H_2O + NO$ is very difficult to balance unless we know some of the coefficients which are found in the balanced equation. If we memorize **3Cu** and **8HNO₃**, the problem of balancing the equation becomes a simple one.

<div align="center">

3Cu will give **3Cu(NO₃)₂**,
8HNO₃ will give **4H₂O, 3Cu(NO₃)₂**, and **2NO**.

</div>

The balanced equation is then

$$3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 4H_2O + 2NO.$$
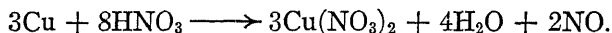
EXERCISES. Balance the following equations:

41. $3Ag + 4HNO_3 \longrightarrow$ $AgNO_3 +$ $NO +$ H_2O

42. $8KI + 5H_2SO_4 \longrightarrow$ $K_2SO_4 +$ $H_2O +$ $H_2S +$ I_2

43. $10FeSO_4 + 8H_2SO_4 + 2KMnO_4 \longrightarrow \quad K_2SO_4 + \quad MnSO_4$
    $+ \quad Fe_2(SO_4)_3 + \quad H_2O$

44. $4Zn + 10HNO_3 \longrightarrow \quad Zn(NO_3)_2 + \quad NH_4NO_3 + \quad H_2O$

45. $2NaIO_3 + 3Na_2SO_3 + 2NaHSO_3 \longrightarrow \quad Na_2SO_4 + \quad H_2O$
    $+ \quad I_2$

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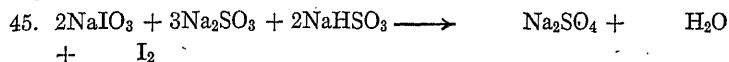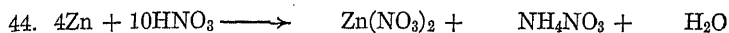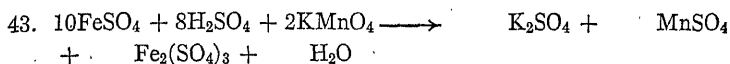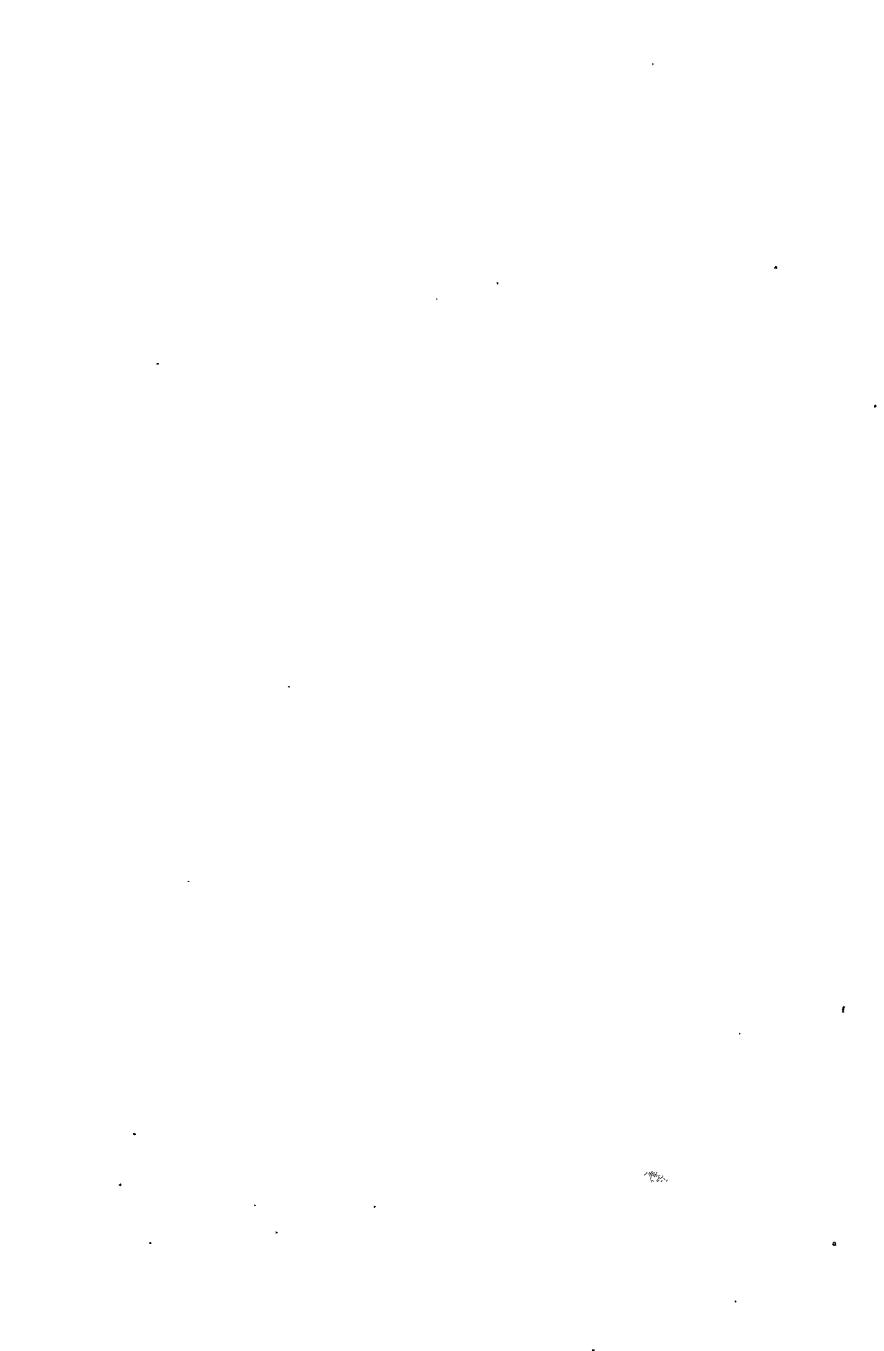
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